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THE ASSOCIATION was organized in Boston, Mass., on June 21, 1882, with the object of providing its members with means of social intercourse and for the exchange of knowledge pertaining to the construction and management of water works. From an original membership of only TWENTY-SEVEN, its growth has prospered until now it includes the names of over **700** men. Its membership is divided into two principal classes, viz.: MEMBERS and ASSOCIATES. Members are divided into two classes, viz.: RESIDENT and NON-RESIDENT, — the former comprising those residing within the limits of New England, while the latter class includes those residing elsewhere. The INITIATION fee for the former class is FIVE dollars; for the latter, THREE dollars. The annual dues for both classes of Active membership are THREE dollars. Associate membership is open to firms or agents of firms engaged in dealing in water works supplies. The initiation fee for Associate membership is TEN dollars, and the annual dues FIFTEEN dollars. This Association has six regular meetings each year, all of which, except the annual convention in September, are held at Boston.

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New England Water Works Association.

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AN EXPERIENCE WITH WATER RAM.

BY CHARLES W. SHERMAN, PRINCIPAL ASSISTANT ENGINEER, METCALF & EDDY, CONSULTING ENGINEERS, BOSTON, MASS.

[*Read January 8, 1913.*]

About three years ago the Northeast Harbor Water Company, experiencing some difficulty on account of the fluctuations of pressure resulting from the operation of a hydraulic elevator in a summer hotel, served notice upon the proprietor that he must install tanks to supply the elevator instead of taking the water directly from the main pipes. The proprietor felt that the demand was unreasonable, and demurred, whereupon the company notified him that they would cut off his water unless he complied with their requirements. Upon this the proprietor brought suit in equity to enjoin the company from cutting off his supply of water. The case was heard in April, 1910, and the result is briefly stated in the following quotation from the *Engineering Record* of March 11, 1911.

"Water for elevators has proved a source of so much contention between water-works superintendents and consumers that a decision by the Maine Supreme Judicial Court in Kimball *v.* Northeast Harbor Water Company, 78 Atl. Rep. 865, deserves attention. The company requested the plaintiff to modify his hydraulic elevator connection in such a way that the water from an 8-in. street main would first pass into a tank through the 4-in. service, instead of directly to the elevator mechanism. The company pressed this request, and as an answer to it the plaintiff brought a bill in equity to restrain the company from shutting off its supply. The Court decided that the use of water for a

hydraulic elevator was a domestic use, within the ordinary meaning of charters to water companies authorizing them to furnish supplies for domestic uses. On this ground it ruled that the company was obliged to furnish water for a hydraulic elevator, if the plaintiff so desired. On the other hand, the Court ruled that the company was justified in asking the plaintiff to build tanks of sufficient capacity to relieve the street mains from the water hammer and other inconveniences caused by operating the elevator directly. These troubles are well known to superintendents, particularly those who have attempted to furnish water under rather high pressure for such purposes. The Court held that the company's request was clearly justified and that no one could successfully maintain that its obligation as a public service corporation to other consumers, as well as a proper regard for the protection of its own property, did not warrant its request. The Court accordingly refused to grant the injunction, leaving the company free to cut off service to the property in question unless the owner made some reasonable provision for operating the elevator."

The writer testified as an expert for the plaintiff, and made some tests in preparation for his testimony, the results of which may be of interest, as well as the principal figures submitted by the Water Company, showing the actual results of the operation of the elevator in question.

The conditions were roughly as follows: The hotel was supplied by a 4-in. pipe, 300 or 400 ft. long, leading from an 8-in. main supply pipe at a distance of some two or three miles from the pond from which the supply is taken. The hydraulic elevator — the only one in town — is of an old type and has a total lift of about 32 ft. The travel of the plunger is about 4 ft., and its diameter is 22 in. It was found that the elevator valve was made to open or close a series of holes, with the intention of making the opening or closing rather slow; and that it was necessary to overhaul 4.5 ft. of valve rope to open or close the valve, or 9 ft. to reverse the elevator. The static pressure at the hotel was about 40 lb. per sq. in., and a relief valve set at 45 lb. had been installed near the elevator.

Nobody seemed to know just how long it took the elevator to make a trip, but it was conceded that it could hardly have been less than 30 sec. Assuming this to be correct, the 22-in. plunger

traveled about 4 ft. (and consequently the displacement was 79 gal.) in 30 sec., or the flow was 158 gal. per min., corresponding to a velocity of less than 3 ft. per sec. in the 4-in. pipe, which is certainly not an excessive velocity. If this could have been checked instantaneously the resulting water ram would have been considerable, but it would obviously have required an appreciable time to overhaul 4.5 ft. of valve rope to shut off the water.

The data available before the Water Company had presented its case were not sufficient to enable the writer to make an estimation of the increased pressure which might have resulted from the operation of the elevator, to which he would care to testify. In order to get some information which might serve as an indication, an experiment was made, through the courtesy of the superintendent of the water works at Ellsworth, where the court was in session. Here a place was found where there was a 4-in. pipe, some 400 ft. long, supplying a locomotive standpipe, where the normal pressure was about 68 lb. This branch, like that at Northeast Harbor, was from an 8-in. main leading from the reservoir at a considerable distance. No method was discovered of drawing water, or of opening and closing the valve, at the same speed as with the elevator, so it was determined to make the test as severe as possible. The pressure gage was attached to a house service pipe about 150 ft. from the locomotive standpipe, and the standpipe valve was opened wide, as rapidly as possible, left open until a condition of steady flow was obtained, and then closed as rapidly as possible. The maximum velocity in the 4-in. pipe is estimated to have been not less than 10 ft. per sec. The time of opening the 4-in. valve was 30 sec., and the time of closing was 20 sec. The pressure dropped almost immediately upon starting the valve from 68 to 28 lb., or to 41 per cent. of the normal; and at the instant of closing the pressure gage registered 134 lb., or 202 per cent. of the normal.

This maximum pressure is not great enough to be dangerous to any well-constructed pipe system, although the sudden fluctuations would doubtless be annoying at times.

The officers of the Water Company presented gage readings showing what the actual fluctuations had been in various parts of

town. The significant figures, as taken down during the testimony, are as follows:

PRESSURES OBSERVED AT VARIOUS PLACES IN NORTHEAST HARBOR DURING OPERATION OF HYDRAULIC ELEVATOR.

POUNDS PER SQUARE INCH.			PER CENT. OF NORMAL.	
Normal.	Highest.	Lowest.	Highest.	Lowest.
56	75	40	135	71
58	60	35	104	60
55	62	32	112	58
32	40	10	126	31
32	50	10	156	31
60	80	40	133	67
58	85	35	147	60
55	75	35	136	63
54	70	25	128	46
51	70	28	137	55
30	50	10	167	33
30	50	8	167	27
28	60	10	213	35

The foregoing figures show that in general the operation of the elevator caused a drop in pressure ranging from 40 per cent. to between 60 per cent. and 70 per cent. when the valve was opened, and an increase in pressure, or water ram, amounting to from 30 per cent. to 50 per cent. of the normal pressure under ordinary circumstances, and sometimes running up to about 100 per cent. increase in pressure.

These results confirm in a general way the conclusions reached by the writer from the experiment described above, — that the pressure might drop about 60 per cent. below normal when the valve was opened, and rise to a maximum of about 100 per cent. above normal at the moment of closing the valve. These fluctuations are sufficient to cause annoyance, but, where the normal pressures are as low as in the cases cited, should not be dangerous to the pipes.

None of these results can be applied to conditions differing materially from those quoted above, but they may serve to give some indication of the extent of the water hammer that may be experienced in a small water-works system from the rapid closing of valves or fire hydrants.

The writer must not be misunderstood as in any way favoring the operation of hydraulic elevators directly from the street main, as a general proposition, as he fully realizes the annoyance, and in many cases, the danger, of such conditions. This particular case seemed to him one where the danger was slight, whatever the annoyance may have been.

DISCUSSION.

S. L. BERRY, ESQ.* (*by letter*).† Reference to Fig. 1 (p. 176), constructed from the formulæ given by Joukowsky, shows that the added pressure in the case of a 4-in. pipe, or a cast-iron pipe 0.48 in. thick, with the water flowing 4 ft. per sec. (for 158 gal. per minute) would be 235 lb. per sq. in. for a valve closure within the time required for the pressure wave to reach a free surface, of large size, and return. In the case of a water-supply system, this time would be difficult to predict, but every enlarged section reached by the wave would reflect pressure relief in accordance with the ratio of its area and physical conditions affecting the velocity of propagation of the wave to those conditions in the pipe in which the ram originated. As the velocity of propagation is, in this case, about 4 370 ft. per sec., the time required for the wave to return from the 8-in. main is 0.183 sec., and at this instant there would be a partial relief of the ram pressure. If the valve is closed in this time the full pressure of 235 lb. would be felt at the valve.

An interconnected system gives very complicated results as far as water hammer is concerned. The primary and most effective remedy is in slow operation of valves. Where this cannot be controlled, relief valves prevent undue ram pressures but have no effect on pressure drop, while air chambers at, or near, the valves minimize both conditions. These are, however, uncertain as to

* San Francisco, Cal.

† Addressed to the Editor of *Engineering Record*.

maintenance of air supply. In general, it may be said that any increase in elasticity in the system, at and near the valve, will decrease the severity of both variations from normal pressure. A central air vessel would tend to prevent extension of the ram to the entire system, but would have no effect upon the neighboring parts when a valve is suddenly closed.

The test conditions at the locomotive standpipe, while showing what was desired in this case, were such that no conclusions can be drawn as to the added pressure in the 4-in. pipe. The diagram before mentioned shows this to be, for a velocity of flow of 10 ft. per sec., 585 lb., for sudden closing within the limits given above. On the arrival of the wave at the 8-in. pipe, this would drop to about 270 lb. and would be reflected to the valve, arriving there 0.183 sec. after closing.

If the 4-in. pipe ran to a reservoir two miles away, the ram for a closure in 20 sec. would be about 125 lb., while for the 4-in. and 8-in. it would be materially less, probably 50 to 60 lb. The gage, being on a small pipe and probably near a dead end, would show a higher pressure than would exist in the 4-in. pipe. If the gage stood at 28 lb. when the closing began, the ram was 106 lb. at that point.

The whole subject of water hammer is most interesting and complicated, and there is a great need for extensive investigation and experiment.

The following is taken from a recent article * by the writer:

When the valve in a pipe line or the regulating mechanism of a water wheel is closed, partly or fully, a decreased velocity and an excess pressure result, the amount of which depends upon the velocity which has been lost, the degree of compression which the water undergoes, and the stretch in the pipe. This increased pressure wave starts at the valve, travels up the pipe with a velocity equal to that which sound would have under similar conditions, and which is dependent upon the same factors which control the ram pressure. In fact, the pressure is calculated directly from the velocity of the wave.

In a pipe line having no safety valves or air chambers, and consisting of pipe of the same diameter and thickness of wall through-

* *Western Engineering*, Vol. 1, p. 713.

out the entire length, the pressure wave travels to the reservoir, where it drops to normal, and a wave of normal pressure travels toward the valve at the same velocity. On reaching this point, the pressure drops below normal by an amount somewhat less than the ram, and a wave of subnormal pressure runs to the reservoir and back. In this simple case a gage at the valve, if so made that it shows the pressures accurately, would rise to the ram pressure and stay there until the wave returned, when it would drop below normal for an equal time. The time of each of these cycles is found by dividing twice the pipe length by the velocity of the wave.

It is necessary to know this when determining the time within which the governor shall close the gates for the reason that it has been found that if the gates are closed before the pressure wave returns, the ram is as heavy as though they had been closed instantaneously. Thus long lines are more difficult to control than short ones, and anything which increases the elasticity of the line increases the time of the cycle, although it also decreases the amount of the supernormal pressure.

With varying diameters and wall thicknesses of pipes, the wave velocity and amount of pressure will be different in each section, and it is necessary to consider them in conjunction to obtain correct results. The pressure conditions at the valve become too involved to be followed very far, but it can be stated that in most if not all installations the lower section produces the most ram. As this influence extends upward, it is necessary to see that the thinner upper walls are not overstrained. If it is found from the diagrams that the lower section will be subject to a ram pressure of 400 lb. and the next, if considered by itself, to 300 lb., the resultant to which the one will fall and the other rise will be found between the two. This may be taken at approximately 350 lb. where the diameters do not vary greatly. Similarly, in the third section, this pressure of 350 lb. will increase the pressure which the section would have to withstand were it not influenced by conditions below it. It is seen that high velocities and rigid pipes below affect the safety of the lighter portions.

There will be a successive dropping of the pressure at the valve as the influence of the upper sections is felt, but the manner of

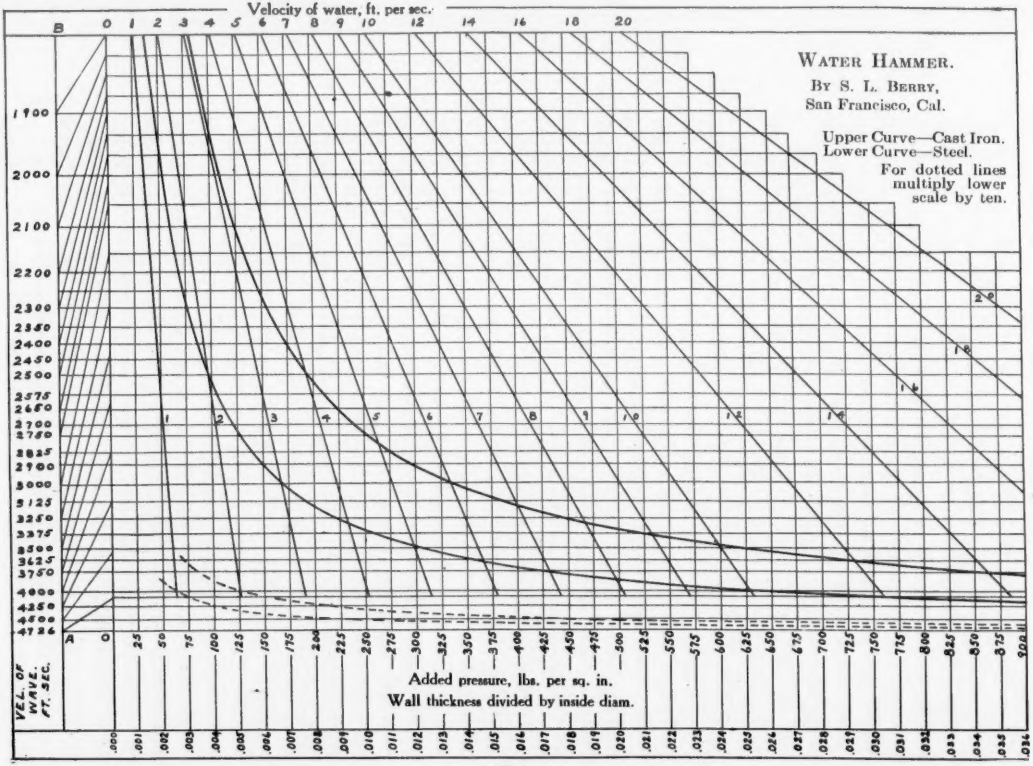
Velocity of water, ft. per sec.
WATER HAMMER.
BY S. L. BERRY,
San Francisco, Cal.
Upper Curve—Cast Iron.
Lower Curve—Steel.
For dotted lines multiply lower scale by ten.
Added pressure, lbs. per sq. in.
Wall thickness divided by inside diam.
VEL. OF WAVE, FT. SEC.

FIG. 1.

Divide wall thickness by inside diameter. Enter table with this figure at bottom. Follow vertically to curve, then to left to "Velocity of wave," then upward along the diagonal line and horizontally to intersection with "Velocity of water," then downward to "Added pressure." The dotted lines are continuations of those above, and in using them the scale of "Wall thickness divided by inside diameter" must be multiplied by 10, all other scales remaining unchanged.

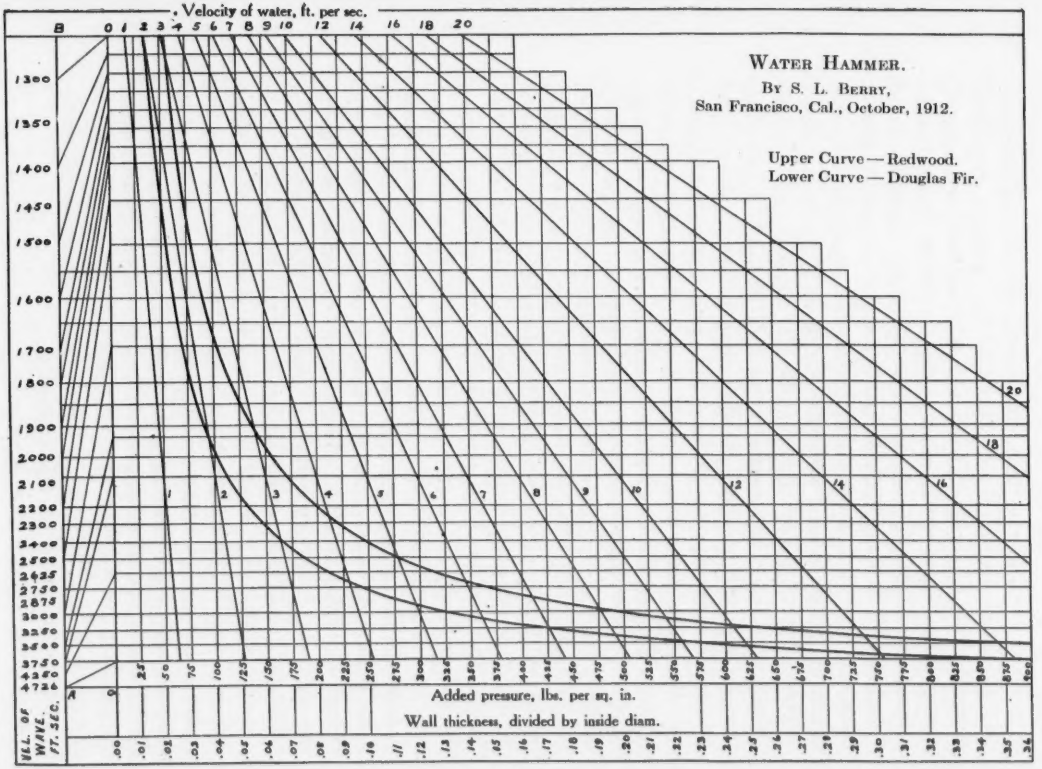
Velocity of water, ft. per sec.
WATER HAMMER.
BY S. L. BERRY,
San Francisco, Cal., October, 1912.
Upper Curve — Redwood.
Lower Curve — Douglas Fir.
Added pressure, lbs. per sq. in.
Wall thickness, divided by inside diam.
VEL. OF WAVE, FT. SEC.

FIG. 2.

Divide wall thickness by inside diameter. Enter table with this figure at bottom. Follow vertically to curve, then to left to "Velocity of wave," then upward along the diagonal line and horizontally to intersection with "Velocity of water," then downward to "Added pressure."

this dropping and its extent become difficult if not impossible to predict when the pipe has several sections of varying diameters and wall thicknesses. Where slow-moving regulating parts and safety devices are installed, the above conditions will not, of course, occur, except when derangement of the machinery eliminates the protection. The study of the worst possible conditions is of value in order to determine the kind and number of safety devices to be installed, and the amount of care in operation necessary to see that all are in good working condition.

The following explanation applies to Figs. 1 and 2. The lower row of figures represents the quotient obtained by dividing the thickness of pipe wall by the internal diameter. Starting at this figure, follow the vertical line to the proper curve for the pipe material, then horizontally to the line *A-B*, showing values of wave velocity in feet per second, then along the diagonal to the line *O-O*, horizontally to the diagonal representing the velocity of the water and vertically downward to the row of figures marked "added pressure." The result will be the ram pressure produced in that particular pipe by closing the gate within the time found by dividing twice the pipe length by the "velocity of wave." Should the gate be only partly closed, take the difference between the velocity before and after the movement instead of the total; it is the velocity lost which produces the ram. In Fig. 1, the dotted curves for cast iron and steel are extensions of the solid ones above, and when used, the lower scale must be read as though multiplied by 10, "added pressure," and all other figures are unchanged. They apply to pipes having ratios of wall thickness to inside diameter ranging from 0.03 to 0.36.

An inspection of the various curves will show that for a given diameter and thickness, steel gives the heaviest ram pressure, followed by cast iron, Douglas fir, and redwood. However, as cast iron is always used with heavy walls, it will be found in practice to exceed steel. Wood stave pipe gives low pressures but long periods of vibration. In these no account has been taken of the bands, as it is believed that the great difference in the elastic conditions will render the effects small.

Experiments prove that a pressure wave reflected from a dead-end becomes doubled in intensity unless some water is flowing

from it. With more than one unit taking water from a header, or from branches of a main line, simultaneous gate closure, or closure at intervals equal to four times the pipe length divided by the average velocity of wave, will produce pressures equal to the sum of the separate effects, while they will tend to equalize each other with movements at intervals equal to twice the pipe length divided by the average wave velocity. In the former case, dependence upon the safety appliance is much increased, and it becomes doubly important that the operator see that these are working properly. In all parts of a line, ram pressures should be kept low enough to prevent the following wave of subnormal pressure from reaching the vacuum limit, for in this case the water column will be broken and violent shocks set up, and the pipe be subject to a collapsing pressure.

The diagrams have been calculated for instantaneous closing of the gates, but, as stated previously, the pressure at the gate will be the same for any time of closing less than that required for the wave to make the trip to the reservoir and back. For a time of closing greater than this the pressure given should be multiplied by the round-trip time and the result divided by the closing time. The maximum pressure will reach the top of the line only when the gate is closed instantaneously, so there will be an advantage in slow closing even within the round-trip time.

For those who desire to study the derivation of the formulæ a list of references is given, which, while probably not complete, is extensive enough to cover the field satisfactorily. The most important and extensive work in this direction has been done by Joukowsky, who had unusual facilities in an experimental plant connected with the Moscow water works. The following are given by Church in his "Hydraulic Motors," while values for the modulus of elasticity of the various materials have been taken from several sources, those for Douglas fir and redwood from Circular No. 189, Forest Service, United States Department of Agriculture, 1912, averaged for green timber.

Let

E = bulk modulus of water, 300 000 lb. per sq. in.
E' = modulus of elasticity of the pipe material,
= 30 000 000 lb. sq. in. for steel,

$=16\,000\,000$ lb. sq. in. for cast iron for usual pressures,
$=1\,600\,000$ lb. sq. in. for Douglas fir (Oregon pine),
$=1{,}061\,000$ lb. sq. in. for redwood.
$E_2 = E$ as modified by elasticity of pipe walls.
C = velocity of wave in water, pipe distention not considered.
C' = velocity of wave in water, pipe distention considered.
r = internal radius of pipe in inches.
g = 386.4 in. sec.
γ = 0.03604 lb. cu. in.
p = excess pressure in lb. per sq. in.
c = velocity of water (ft. per sec. or) in. per sec.
t = thickness of pipe wall in inches.
T = time of closing valve, sec.
T_r = time for round trip of wave to reservoir and back.
R_d = wall thickness divided by internal diameter.

When pipe distention is not considered,

(1) $$C = \sqrt{\frac{Eg}{\gamma}} = 4726 \text{ ft. per sec.}$$

(2) $$p = c\sqrt{\frac{E\gamma}{g}} = 63.3c \text{ (ft. per sec.).}$$

Considering the elasticity of the pipe-walls,

(3) $$C' = \sqrt{\frac{E_2 g}{\gamma}} \text{ in which}$$

(4) $$E_2 = \frac{EE't}{tE' + 2rE} \text{ and the velocity of the wave.}$$

(5) $$C' = 103.5\sqrt{E_2} \text{ in in. per sec. and}$$

(6) $$C' = 8.625\sqrt{E_2} \text{ ft. per sec.}$$

(7) $$p = \frac{cC'\gamma}{g} \text{ in. sec. units.}$$

(8) $$= 0.000093cC' \text{ in. sec. units.}$$

(9) $$= 0.0134cC' \text{ for } c \text{ and } C' \text{ in ft. per sec.}$$

(10) When T is greater than T_r, pressure $p_1 = \frac{pT_r}{T}$.

The following formulæ have been deduced from the curves of the diagrams which were constructed from the above. In the diagrams the ratios of wall thickness to internal diameter are given as being more convenient than ratios involving the radius. The values of E_2 may be found, if desired, as the curves are equilateral hyperbolas, with the ratios R_d for abscissæ and for ordinates the relation $\frac{E}{E_2} - 1$ referred to the asymptotes. The constant K in the equation

$$R_d\left(\frac{E}{E_2} - 1\right) = K$$

varies inversely as the modulus of elasticity of the pipe material and has a value of $\frac{300\ 000}{E'}$, giving results as follows:

K for steel $=0.01$
Cast iron $=0.02$
Douglas fir $=0.1875$
Redwood $=0.2825$

From the above:

(11) $$E_2=\frac{E}{\frac{K}{R_d}+1}.$$

For example, for steel pipe and $R_d=0.008$,

$$E_2=\frac{300\ 000}{\frac{0.01}{0.008}+1}=\frac{300\ 000}{2.25}=133\ 333 \text{ lb. sq. in.}$$

It will be noticed in the formulæ that the effect of pipe extension is treated as producing a virtual modification of the bulk modulus of water. The diagonals between the lines *A-B* and *O-O* are to permit the use of straight lines for water velocity. It follows also, from the formulæ given above, that the velocity of wave in a pipe of any material having a modulus of elasticity E',

$$C'=\frac{4726}{\sqrt{\frac{300\ 000}{E'R_d}+1}}.$$

(12) $$C'=\frac{4726}{\sqrt{\frac{K}{R_d}+1}} \text{ in ft. per sec.}$$

By inserting the value of C' from (12) in (9) and reducing,

(13) $$p=c\left(\frac{63.3}{\sqrt{\frac{K}{R_d}+1}}\right)$$

with c expressed in ft. per sec. and p in lb. per sq. in.

From (11)

$$\frac{K}{R_d}+1=\frac{E}{E_2}, \text{ therefore } p=c\left(\frac{63.3}{\sqrt{\frac{E}{E_2}}}\right).$$

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WATER RAM IN DISTRIBUTION SYSTEM, HARTFORD, CONN.

BY CALEB MILLS SAVILLE, CHIEF ENGINEER, HARTFORD WATER WORKS.

[*Read January 8, 1913.*]

The subject of Mr. Sherman's paper is of especial interest to me just at this time because the Water Department at Hartford also has been having recently some experience with water ram. A year ago this month the 30-in. supply main leading from the reservoirs to the city broke late in the evening of one of the coldest days of the year. One month later a similar misfortune happened to the 20-in. supply main in Asylum Street, and this year, only about a month ago, an 8-in. pipe in Church Street also broke. In casting about to explain these occurrences a very probable cause seemed to be the method of operating the standpipes for filling locomotives at the Union Station of the New York, New Haven & Hartford Railroad. While the break in the 30-in. main was located at a point about 1.5 miles distant from the Union Station, the Asylum and Church Street breaks were within a few hundred feet from the standpipes. As all of these mains let go immediately after the locomotive tanks had been filled, the occurrence of each break greatly strengthened the suspicion of the probable cause. As the result of the investigations, and after conference with the railroad people, it is probable that the trouble can be obviated in a manner satisfactory to all parties.

Several ways of handling this matter have suggested themselves: (1) By a slower motion valve on the standpipe. This is objected to by the railroad people on account of delay to train service. (2) The use of a water cushion valve on the standpipe which would act similar to the air checks on doors. This device is now in operation in various places and when new works very satisfactorily. After constant use, however, the parts wear and if repairs are not made the conditions of ram become as bad as before installation. (3) An air pressure tank or chamber may be

installed so devised that theoretically at least the shock of the quick closing valve will be mostly taken up by an air cushion. Such a device is in operation in several places, but it is understood to be not entirely satisfactory. This condition may be due, however, to a defect in installation rather than to anything inherent in the system. (4) An elevated and independent tank may be used, and this from a water-works standpoint is probably the most satisfactory solution of the problem. In this case the water may be drawn out as quickly as desired and the tank refilled by a steady stream that will be automatically and gradually cut off as the tank is filled. Unfortunately this method of solving the problem is not always feasible either on account of esthetic conditions which forbid an unsightly tank or on account of the cost of an architecturally satisfactory structure.

The diagrams presented are perhaps the best evidence needed to show the stress that is put on the pipes when quick motion valves are allowed on locomotive standpipes in cases where no effort is made to prevent ram.

Fig. 1 is from a recording pressure gage located on the 8-in. lateral directly supplying the standpipe. It is to be noted that the extreme vibrations of the pen show a total length representing about 120 lb. per sq. in.

Fig. 2 is from a recording pressure gage located in the Water Department office at City Hall about half a mile from the Union Station. This diagram is particularly interesting as showing that the water ram impulse is transmitted to considerable distance through a distribution system, and with a decidedly appreciable force. A few of the principal deflections have been marked here and there to identify the same period on these two charts. A number of observations during the period of filling the locomotive tanks have given the following information, which is believed to be fairly representative of the average conditions which obtain.

Capacity of locomotive tanks (through service)	6 000 to 7 000 gal.
Quantity usually drawn (meter readings)	4 230 gal.
Length of time flow is maintained	2 min. 50 sec.
Velocity in lateral	9.50 ft. per sec.
Size of lateral	8-in.
Size of street main	12-in. and 16-in.

Beside that from locomotive standpipes, another source of water ram may be found in the operation of steam fire engines. On December 13, at 2.15 A.M., an alarm was rung in for a fire in the building occupied by Smith & Northam on State Street, Hartford.

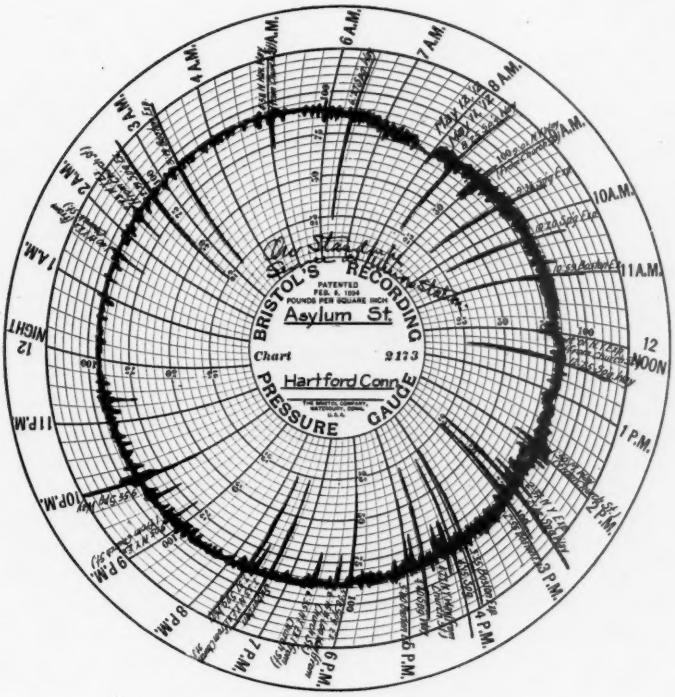

FIG. 1.

CHART FROM PRESSURE GAGE ON LINE SUPPLYING LOCOMOTIVE STANDPIPE.

The building was supposed to contain a considerable quantity of hay and was located in a district where serious results were apprehended if the fire was not quickly controlled. Besides other apparatus, four steamers responded. Two of them were of the

large self-propeller type, capable of delivering 1 200 gal. per min. each. The other two were of the ordinary type, one of 900 gal., the other of 600 gal., each per minute. Besides the above, the fire pumps at the nearby car barns of the Connecticut Company were

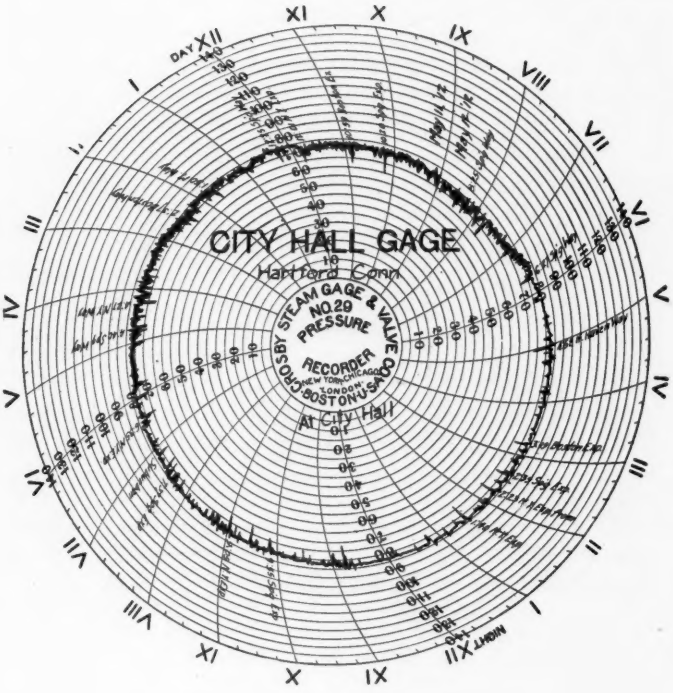

FIG. 2.

CHART FROM PRESSURE GAGE AT CITY HALL.

put in service. The hose line system consisted of the following lines: Two 3-in., four 2½-in., and three 1½-in. lines. The Venturi meter on the supply main at the effluent gate house indicated a draft for this fire of about 350 000 gal., the rates of draft in excess of the ordinary consumption being as follows:

Ten Minute Intervals.	Gallons per Hour.	Ten Minute Intervals.	Gallons per Hour.
1st period	125 000	9th period	110 000
2d	190 000	10th	130 000
3d	200 000	11th	140 000
4th	240 000	12th	100 000
5th	195 000	13th	70 000
6th	160 000	14th	30 000
7th	170 000	15th	20 000
8th	170 000	16th	30 000

Fig. 3 is from the recording pressure gage located in the Water Department office about 500 ft. from the location of the fire. The gage and the steamer were on the same main. Particular attention is called to the frequency of the vibration, which was such as to cause the pen to paint a continuous blotch rather than to show the individual movements. It is also to be noted that the extreme length of vibration corresponds to about 110 lb. pressure per sq. in. The withdrawal of some of the fire engines is well marked, especially at about 3.30 A.M., by the sudden cessation of the extreme amplitude of vibration.

In connection with this diagram it may be of interest to state that the city of Hartford has recently passed through a rather disturbing period due to low rainfall and the excessive calls that have been made on the storage in the reservoirs. In order to take every precaution possible to conserve the supply and to put off as long as possible the evil day of turning to the Connecticut River for an emergency supply, the gates on the supply mains were throttled down during the late afternoon and night. The intention was to keep the pressure during this period at about the same point as it stood during the day hours of maximum consumption. A drop in pressure of about 15 lb. per sq. in. was made in this manner, and the Venturi meter records indicate a saving of at least a quarter of a million gallons per day. By good fortune there are two fire engine houses not far from the city line and also near the main gates on the supply main. Two men were stationed at each of these houses, and on an alarm of fire they open the gates

as soon as possible. A number of alarms have come in during this period, but at no time has there been any lack of pressure when the engines arrived. The ordinary night consumption at this season of the year is at a rate of about 4 000 000 gal. per day.

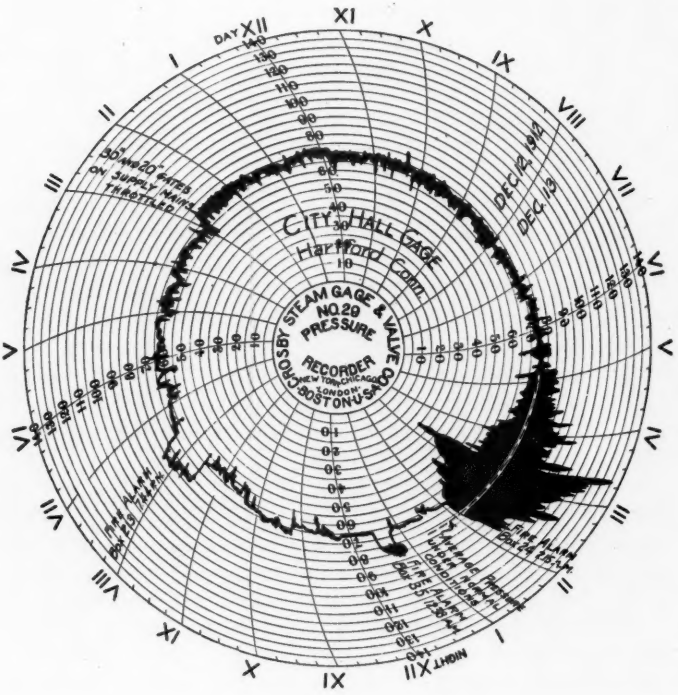

FIG. 3.

VARIATION IN PRESSURE CAUSED BY FIRE ENGINES.

The time of closing the gates appears on the diagram about 3 P.M., and the effect of opening up on account of other fire alarms the same night is shown at 8 P.M., 12.45 A.M. and 2.15 A.M. Ordinarily the gates are opened each morning at 5.30 A.M.

DISCUSSION.

MR. G. A. CALDWELL. Has anybody here ever used a reducing valve to obviate water hammer, especially in connection with filling locomotive engine tanks?

MR. SAVILLE. I haven't had any. I should like to get some information on that subject.

MR. CALDWELL. I think if you would test that out it would help to you overcome your difficulty. The principle of a regulator is that by reducing the size of the opening it increases the velocity of the water passing through the smaller opening. When you close your valve on the outlet end, you have a back pressure which closes off your regulator, and, therefore, you will not get the hammer back of the regulator, — that is, I do not think you will. At all events, I believe a test along those lines would be worth while, and I think the result would be satisfactory and would save you some money.

MR. SAVILLE. I am certainly glad to get the suggestion.

MR. F. W. DEAN.* It seems to me that using a reducing valve would be equivalent to using a slow moving valve, which the railroad company in the case mentioned objected to.

I have experimented on a small scale recently at my house by connecting a refined test gage permanently in my bath room to the water pipe, and it is very interesting to see how it behaves. When the flush valve of the water closet is opened, the pressure immediately drops from 73 lb. to 20 lb. Of course if it went back quickly it would make a severe water hammer, but as these flush valves close by the rising of a ball float, the action is slow and nothing happens. It is interesting to observe how water impulses travel apparently all over the town. The hand of this gage is never still, but is constantly varying from 1 to 3 lb.

Undoubtedly the best method of suppplying the service required by railroads would be to have a float valve which would deliver water into a tank. The locomotive would get the water quickly from the tank, but the float valve would close so slowly that there would be no water hammer.

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* Mill Engineer and Architect, Boston, Mass.

MR. JOHN DOYLE.* I should like to ask Mr. Saville at what elevation above the city proper the break in the 30-in. force main of which he spoke occurred?

MR. SAVILLE. I think it was an elevation of about 40 or 50 ft.

MR. DOYLE. Was it anywhere near the reservoir?

MR. SAVILLE. No; it was five miles from the reservoir.

MR. DOYLE. We had some trouble in Worcester on a 40-in. main, but it was near a regulating valve, and the trouble occurred after there had been several large fires. We had, I think, two or three breaks on the 40-in. main. Those breaks were caused in my opinion by water hammer, as the pipe burst right through the center of the bottom in all cases. Through the orders of Mr. Batchelder, the commissioner, we put on three $2\frac{1}{2}$-in. Ross relief valves and connected them together, and we haven't had any trouble at this point since. It has done away with the hammer. I have recently taken some observations there, have had a gage put on at this particular place, and everything is working first rate. The last time this 40-in. main broke was nearly a quarter of a mile away from where our regulating valves are located, down on the main thoroughfare, but the conditions were the same as they were at the time of the break up nearer the regulating valves. The pipe burst right through the center from bell to spigot. After taking the pipe out I noticed that it was comparatively dry at the top, two thirds of the upper part of it, showing that the water hadn't reached it for some time.

MR. ALLEN HAZEN.† This question of railroad supplies is a very important one, and one that gives much trouble in many works. I have been advising some of my clients not to permit direct pipe connections to feed locomotives, but have advised that such supplies be furnished only through tanks. This may be an expensive method, but it is a sure one. If there is an easier and simpler way of performing the service without danger of water ram, we should all be glad to know of it. Perhaps the incoming administration will take up this subject and see if a standard procedure can be adopted, and if it can be, it will add to the many good works that the Association already has to its credit.

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* General Foreman, Water Department, Worcester, Mass.

† Civil Engineer, New York City.

I believe it to be a fact that the tighter the pipe system is made, the more water hammer is experienced. Where pipe systems are very tight and all the services are metered, and leaks have been thoroughly and systematically stopped, it is necessary to be very careful about quick closing valves, or anything else tending to make water hammer, but in pipe systems that are leaky and where the services are not metered, every leak and every service is a relief valve, and there is not much water hammer.

Now water is getting to be better and more valuable, and it is worth while to take more care to prevent it from wasting. Pipe systems of the future are going to be tight, and the matter of water hammer will be even more important than it has been.

At Des Moines, Ia., where the pipe system is very tight and where water hammer had been bothersome, a large steel tank, corresponding to a boiler, was connected with the pipes near the pumping station, which is quite near to the business center of the city, and this tank was kept full or partly full of air by an air pump. It was found that this tank steadied the service in a satisfactory way.

It may be that devices of this kind may prove advantageous, but in the meantime, quick closing valves are to be discouraged on all pipes connected with a system.

MR. CHARLES E. PEIRCE.* Mr. Chairman, speaking of a steel air tank, I would say that one has been installed in the works which I represent, and it certainly has helped to relieve the water hammer, although it has not been entirely satisfactory. The tank is quite a large one, about 10 ft. high by 6 ft. wide. We have a pretty high pressure. The highest pressure when the standpipe is full is about 150 lb. at sea level. We carry from 130 to 140 lb. We have elevators from which we get some trouble. We used to get it at the station on our steam pump more particularly, but we have not used the pump during the last year to any great extent, as we have installed electric service there.

MR. JOHN DOYLE. I would suggest that a good way to avoid trouble in the down-town district is to put in heavy pipes and do first-class work. In my opinion that will obviate any trouble. We never have had any trouble in Worcester from the elevators.

* Superintendent East Providence Water Company, Rumford, R. I.

We have something like 300 elevators and carry a direct pressure on our high service system. At City Hall we have a pressure of 140 lb. to the square inch, and we have never had any trouble at all with water hammer on our main system through the city, nor on any of our elevator pipes.

MR. F. L. FULLER.* The system at Winchendon, Mass., was supplied with relief valves when the works were built. I cannot give any information as to how they have worked. They were installed in 1892.

MR. E. S. TUCKER (*by letter*).† Our system is equipped with relief valves. We have not paid much attention to them and we are not troubled with water hammer.

MR. JOHN C. WHITING (*by letter*).‡ There is not a relief valve in the Newton system, though at one time we seriously considered putting them on two lines from which locomotive standpipes drew their supply and from which considerable trouble was experienced from water hammer. We found the trouble was caused largely by the rapidity with which these standpipe gates were opened and closed, and as a very coarse thread was used on the spindle, it took comparatively few turns to fully open or close.

The case was presented to the Railroad Company with request that gates having a finer thread be substituted; since installing them practically no trouble has been caused by the standpipes.

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* Civil Engineer, Boston, Mass.
† Water Commissioner, Winchendon, Mass.
‡ Water Commissioner, Newton, Mass.

DECARBONATION AS A MEANS OF REMOVING THE CORROSIVE PROPERTIES OF PUBLIC WATER SUPPLIES.

BY GEORGE C. WHIPPLE, OF HAZEN & WHIPPLE, CONSULTING ENGINEERS, NEW YORK CITY; PROFESSOR OF SANITARY ENGINEERING IN HARVARD UNIVERSITY.

[*Read March 12, 1913.*]

Almost all natural waters used for public water supply are corrosive of the pipes through which they flow and the metal structures with which they come in contact. Various causes contribute to this corrosive property, but, omitting those of minor importance or of significace in special cases only, the three primary factors that water-works engineers need to consider are carbonic acid, oxygen, and the pipes themselves.

Thus far the last of these has received most attention. Much care has been taken in the choice of metals used, in the quality of the metals selected, and in the protective coating employed. Many questions as to the relative value of wrought iron and steel, the use of protective metals such as tin and zinc, the use of asphalt, coal tar, cement, and other coatings, have been actively discussed by this Association on previous occasions. Comparatively little attention has been given to measures for removing the corrosive properties of the water itself, that is, for getting rid of the carbonic acid and dissolved oxygen, although both measures have been practiced to some extent in different parts of the world. Thus, at Coolgardie, in Australia, it has been suggested that the oxygen be removed from the water by a vacuum process in order to reduce the corrosion in the long steel pipe line. The removal of oxygen from hot water by exposure to the air has been suggested and used with some success in preventing the corrosion of hot water pipes. Carbonic acid is removed from certain ground-waters in Germany and elsewhere by aëration as an incident to the iron removal process, while in England it is neutralized by the use of chalk.

Reduction of the corrosive properties of water by oxygen removal is a very difficult matter and could not be applied to a public water supply without great expense. It would also be

undesirable and need not be considered further. The decarbonation of water, that is, the removal or neutralization of the carbonic acid gas, is a much simpler matter and one that can be accomplished practically. It is the removal of the corrosive properties of water by decarbonation that forms the subject of the present paper. The methods discussed are aëration and the use of soda and lime. The latter is so intimately connected with the hardness of water that this important subject may be logically considered first.

Softness of New England Waters.

Most of the water supplies of New England are extremely soft. The Massachusetts State Board of Health, in its annual report for 1909, gave the hardness of 153 surface waters and 90 ground waters used for public water supplies in the state. These may be grouped as follows:

TABLE 1.

The Hardness of Certain Massachusetts Water Supplies.

(Mass. State Board of Health, 1909).

Hardness, Parts per Million.	Number of Supplies where the Average Hardness was between the Figures Indicated.			Per Cent. of Supplies where the Average Hardness was between the Figures Indicated.		
	Surface Waters.	Ground Waters.	Total.	Surface Waters.	Ground Waters.	Total.
0 to 5	30	5	35	19.6	5.5	14.4
6 to 10	40	9	49	26.2	10.1	20.2
11 to 15	29	10	39	19.0	11.0	16.1
16 to 20	18	15	33	11.8	16.6	13.6
21 to 30	19	20	39	12.4	22.3	16.1
31 to 40	9	11	20	5.9	12.3	8.2
41 to 50	2	11	13	1.3	12.3	5.3
51 to 60	3	5	8	2.0	5.5	3.3
61 to 70	1	1	2	0.6	1.1	0.8
71 to 80	1	1	2	0.6	1.1	0.8
81 to 90	0	0	0	0.0	0.0	0.0
91 to 100	1	1	2	0.6	1.1	0.8
101 or over	...	1	1	....	1.1	0.4
Total,	153	90	243	100.0	100.0	100.0

It will be seen from these figures that half of the surface waters are softer than 10 parts per million, and three quarters of them are softer than 20 parts per million. In only 5 per cent. of the surface supplies does the hardness exceed 50 parts per million. The ground water supplies are slightly harder, but they also are, on the whole, very soft. Half of them are softer than 25, and nearly nine tenths of them are softer than 50 parts per million. The hardest waters are found in Berkshire County, in the western part of the state, where limestone exists. A few supplies near the seacoast are doubtless influenced to some slight extent by the sea water.

The large cities of the state are all supplied with very soft water, as the following figures show:

TABLE 2.

HARDNESS OF THE WATER USED BY THE CITIES OF MASSACHUSETTS WHICH HAD POPULATIONS OF MORE THAN 25 000 IN 1910.

City.	Population.	Hardness. Parts per Million.
Boston, Metropolitan District,	1 046 630*	12
Worcester,	145 986	11
Fall River,	119 295	7
Lowell,	106 294	19
Cambridge,	104 839	29
New Bedford,	96 652	7
Lynn,	89 336	15
Springfield,	88 926	12
Lawrence,	85 892	14
Holyoke,	57 730	20
Brockton,	56 878	5
Haverhill,	44 115	18
Salem,	43 697	20
Newton,	39 806	28
Fitchburg,	37 826	5
Taunton,	34 259	5
Waltham,	27 834	38
Gloucester,	24 398	4

The water supplied to the Metropolitan District of Boston, with a population of over a million people, has a hardness that averages about 12 parts per million; the supply of Worcester, the next

*Estimate for 1911.

TABLE 3.

HARDNESS OF THE WATER SUPPLIES OF LARGE AMERICAN CITIES.

The following figures represent the approximate average hardness for the year, in parts per million, based on the best available analyses. In some cases the seasonal variations from the average hardness are very great.

[ ] = raw water.

City.	Population, 1910.	Water Supply.	Hardness.			Year.	References and Remarks.
			Alkalinity.	Incrustants.	Total Hardness.		
New York:	4 766 883	Esopus Creek.	16	4	20	1903	New supply. Not yet used.
Manhattan...		Croton River.	36	2	38	1907	Ann. Rep., Dept. W. S., G. & E.
Bronx.....		Bronx River.	27	5	32	1907	Ann. Rep., Dept. W. S., G. & E.
Brooklyn.....		Ridgewood, wells and streams.	16	16	32	1907	Ann. Rep., Dept. W. S., G. & E.
Queens.....		Chiefly wells.	11 to 183	1 to 171	12 to 354	1907	Some of the wells are affected by sea-water.
Richmond....		Chiefly wells.	76 to 143	33 to 101	144 to 179	1903	
Chicago.....	2 185 283	Lake Michigan.	116to124				L. M. Water Com.
Philadelphia....	1 549 008	Delaware River.	24	19	43	1900	G. C. W.
		Schuylkill Rriver.	41	47	88	1911	
St. Louis.....	687 029	Mississippi River.	[135]−50	[24]−41	[159]−91	1908	Wall: Am. Soc. C. E., Vol. LX, p. 187.
Boston.....	670 585	Sudbury and Nashua Rivers.	10*	2*	12	1909	Mass. State Bd. Health.
Cleveland.....	560 663	Lake Erie.	85	7	92	1912	Jackson's Rep., p. 116.
Baltimore.....	558 485	Jones Falls Creek	70	−4	66	1910	June only.
		Gunpowder Creek.	45	−5	40		
Pittsburgh.....	533 905	Allegheny River.	25	25	50	1910	Annual Report.
Detroit.....	465 766	Detroit River.	85	4	89	1909	Dole: W. S. & I. P. No. 236, p. 126.
Buffalo.....	423 715	Niagara River.	98	11	109	1909	Dole: W. S. & I. P. No. 236, p. 116.

San Francisco...	416 912	Surface and ground water.			100	1911	Allen Hazen.
Milwaukee.....	373 857	Lake Michigan.	108	7	115	1910	Sewerage Commission.
Cincinnati.....	364 463	Ohio River.	[40]−45	38−46	[78]−91	1911	Ann. Rep., Water Dept.
Newark.....	347 469	Pequannock River.	15			1911	State Bd. Health.
New Orleans....	339 077	Mississippi River.	[92]−38	[22]−24	[114]−62	1909	Earl.
Washington.....	331 069	Potomac River.	30	49	79	1909	
Los Angeles.....	319 198	Los Angeles River.	200	61	261†	1908	
Minneapolis....	301 408	Mississippi River.	154	4	158	1909	Dole: W. S. & I. P. No. 236.
Jersey City.....	267 779	Rockaway River.	35	7	42	1911	
Kansas City....	248 381	Missouri River.	166	64	230		
Seattle.....	237 194	Cedar River.			14	1913	Jacobsen.
Indianapolis....	233 650	White River.	240	5	249	1909	Dole.
Providence.....	224 326	Pawtuxet River.	10	10	13	1912	State Bd. Health.
Louisville.....	223 928	Ohio River.	[66]−53	29−38	[95]−91	1911	Ann. Rep., Water Dept.
Rochester.....	218 149	Hemlock Lake.	65	6	71	1912	City Chemist.
St. Paul.....	214 744	Natural lakes.					
Denver.....	213 381	Impounding reservoir.	95	70	165		
Portland, Ore....	207 214	Impounding reservoir.					
Columbus.....	181 548	Scioto River.	[151]−40	[102]−53	[253]−93	1909	Ann. Rep., Water Dept.
Toledo.....	168 497	Maumee River.	[145]−119	[76]−105	[221]−224		
Atlanta.....	154 839	Chattahoochee River.	9				
Oakland.....	150 174		165	15	180	1910	
Worcester.....	145 986	Impounding reservoir.			11		
Syracuse.....	137 249	Skaneateles River.			98		
New Haven.....	133 605	Lake Whitney			33	1901	State Bd. Health, 1901, p. 329.
		Dawson Lake.			15		

*Estimated.

† New supply from Owens River has hardness of 158.

TABLE 3.—*Continued.*

City.	Population, 1910.	Water Supply.	Hardness.			Year.	References and Remarks.
			Alkalinity.	Incrustants.	Total Hardness.		
Birmingham	132 685	Cahaba River.					
Scranton	129 861	Impounding reservoir.					
Richmond	127 628	James River.	[39]–36				
Paterson	125 600	Passaic River.	25	20	45		
Omaha	124 096	Missouri River.					
Fall River	119 295	Watuppa Lake.			7		
Dayton	116 577	Wells.	275	15	290	1904	State Bd. Health
			[200]	[60]	[260]	1911	
Grand Rapids	112 571	Grand River.	190–225	50–85	240–280		*Engineering Record*, Vol. 64.
Nashville	110 364	Cumberland River.					
Lowell	106 294	Driven wells.			19		
Cambridge	104 839	Stony Brook.			29		
Spokane	104 402		130	24	154		Pegg.
Bridgeport	102 054	Impounding reservoir.			8		State Bd. Health, 1896, p. 295.
Albany	100 253	Hudson River.	40	32	72	1912	Geo. E. Willcomb.

largest city, has a hardness of only 11 parts per million; and Fall River, the third city, 7 parts per million. The Lowell water supply, taken from driven wells, has a hardness of 19, and the Cambridge water supply, with its reservoirs quite near the city, shows a hardness of 21 parts per million in its main reservoirs, which increases to 29 as it passes through Fresh Pond.

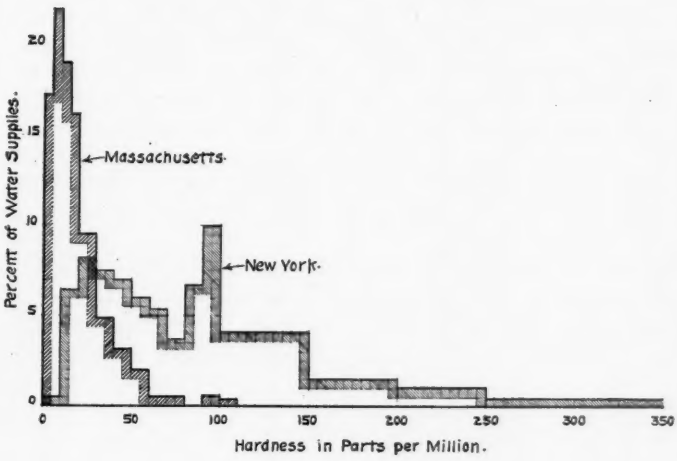


FIG. 1.

CLASSIFICATION OF THE PUBLIC WATER SUPPLIES OF MASSACHUSETTS AND NEW YORK, ACCORDING TO HARDNESS.

For comparison with these figures the hardness of the water supplies of some of the largest cities of the country is given in Table 3. It will be seen that no large city in the country has a water supply that approaches in softness that of the Metropolitan District of Boston. The hardness of the water supplies of New York State is shown in Table 4.

TABLE 4.

CLASSIFICATION OF THE PUBLIC WATER SUPPLIES OF NEW YORK STATE ACCORDING TO HARDNESS.

(From analyses published in the Annual Report of the State Department of Health for 1910, page 280.)

Hardness, Parts per Million.	Number of Supplies where Hardness was between the Figures Indicated.	Per Cent. of Supplies where the Hardness was between the Figures Indicated.
0 to 10	1	0.3
10 to 20	19	6.3
20 to 30	25	8.2
30 to 40	22	7.3
40 to 50	21	6.9
50 to 60	18	5.9
60 to 70	16	5.3
70 to 80	11	3.6
80 to 90	20	6.7
90 to 100	30	9.9
100 to 150	61	20.2
150 to 200	22	7.3
200 to 250	17	5.6
250 to 300	5	1.6
300 to 400	5	1.6
400 to 500	4	1.3
500 to 600	4	1.3
600 to 700	0	0.0
700 to 800	2	0.7
Total,	303	100.0

ADVANTAGES OF SOFT WATER.

Soft waters have a more agreeable feel to the skin when used for bathing, and are less likely to cause the hands to chap. They do not curdle with soap, and deposits of calcium soaps do not form in the pores of the skin. They readily form suds. Soft waters have a greater cleansing power both for the skin and for fabrics.

Hard waters require larger amounts of soap to produce suds, and the soap consumption increases quite regularly with the hardness of the water. It has been calculated that the increased cost of soap used by a community amounts to 10 cents per million gallons of water for each part per million of hardness. This is based on a

water consumption of 100 gal. per capita daily, and assumes that only one gallon per day is completely softened with soap, the cost of soap being taken at 5 cents per pound. For example, the water of New York City, with a hardness of 35 parts per million, imposes on the water consumer a cost of $2.30 per million gallons more than the water of Boston, with a hardness of 12 parts per million. One of the advantages of the new supply of New York City, that is to be derived from the Catskills, will be its lower hardness than that of the present Croton supply.

Hard waters are also objectionable for various industrial uses and steam production. Soft waters are said to be more satisfactory than hard waters for cooking vegetables, for making tea, and other household operations.

These are all matters that are well known to water-works engineers, and do not need to be elaborated.

Disadvantages of Very Soft Water.

The disadvantages of very soft waters relate to the effect that they have on the pipes through which they are distributed. This brings in two very different problems, both of considerable importance, namely, lead poisoning, and the red water plague.

Lead Poisoning.

Not much has been heard lately in regard to lead poisoning caused by public water supplies. In years past it was a serious problem in many places, and within ten years the annual reports of the Massachusetts State Board of Health contain numerous references to the subject, notably in connection with the water supplies of Lowell, Milford, Hopedale, Milton, Gilbertsville, Norwood, Fairhaven, New Bedford, and Kingston. Three important reports are worth noting, namely:

"An Investigation of the Action of Water upon Lead, Tin, and Zinc, with Special Reference to the Use of Lead Pipes with Massachusetts Water Supplies." By H. W. Clark. (Annual Report, 1898, page 541.)

Report of Dr. F. L. Morse on Lead Poisoning. (Annual Report, 1899, page 31.)

"Continuation of an Investigation of the Action of Water upon

Metallic or Metal Lined Service Pipes." By H. W. Clark and F. B. Forbes. (Annual Report, 1900, page 487.)

These investigations showed that the primary active agent in causing water to attack lead pipe was dissolved carbonic acid gas, dissolved oxygen being an important contributory factor. Certain chemical constituents, such as lime, exerted a deterrent influence, especially those which tended to cause a protective coating to form on the pipe. In no case was a large amount of lead found in water that had a hardness of more than 50 parts per million, and very seldom when the hardness was more than 25 parts per million. While it may be fairly said that hard waters protect against lead poisoning, it is not fair to infer that soft waters necessarily attack lead pipes and cause poisoning, for not all soft waters contain large amounts of carbonic acid. Of two waters, one hard and one soft, which contain the same amount of dissolved carbonic acid, the soft water would probably have the greater action on lead pipes.

Generally speaking, dissolved carbonic acid is higher in ground waters than in surface waters, but in swampy or peaty waters that are more or less stagnant, where bacterial action is vigorous, it may be relatively high. Such waters in New England are apt to be soft, hence the soft waters are often associated with lead poisoning.

In middle England, where many of the cities are supplied from so-called " moorland " sources, there were repeated recurrences of lead poisoning, and at one time the issue was a vital one. Some of the most valuable writings on the subject date from that time, and lead poisoning is given prominence in most English text-books on water supplies.

It is interesting to note that the problem of lead poisoning has been solved in two different ways, — in New England by abandoning the use of lead, and in England by removing the carbonic acid from the water.

Abandonment of Lead Pipe in Massachusetts.

Early in the history of American water supplies, when the use of hot water became general, practice set against the use of lead pipe for carrying hot water, brass being substituted.

The State Board of Health of Massachusetts has consistently advised against the use of lead pipe for house service connections in places where the water was found to act on this metal, and has recommended cement-lined pipe or tin-lined lead pipe having a thick layer of tin. Wrought-iron and steel pipes, generally galvanized, have been also used, but waters that will corrode lead will also cause these pipes to rust.

The annual report of the Massachusetts State Board of Health for 1905 (page 197) gave a list of the materials used for service pipes in the cities of the state, and from the data there given the following table has been made, the different water supplies being classified according to hardness from data given elsewhere in the report:

TABLE 5.

SERVICE PIPES USED IN MASSACHUSETTS CITIES CLASSIFIED ACCORDING TO THE HARDNESS OF THE WATER.

(Compiled for the Annual Report of the Massachusetts State Board of Health, 1905, page 197.)

Hardness, Parts per Million.	Number of Cities Using Chiefly the Service Pipes Indicated.				
	Lead or Lead-Lined Pipes.	Tin-Lined Pipes.	Cement-Lined Pipes.	Galvanized Iron (or Steel) Pipes.	Total.
Surface Water Supplies.					
0 to 10	9	2	14	19	40
11 to 20	9	0	3	9	21
21 to 100	0	1	0	10	11
Ground Water Supplies.					
0 to 10	1	0	5	1	7
11 to 20	2	2	7	5	16
21 to 50	4	1	10	14	29
51 to 100	0	0	1	5	6
					130

TABLE 5.—*Continued.*

Hardness, Parts per Million.	Per Cent. of Cities Using Chiefly the Service Pipes Indicated. Lead or Lead-Lined Pipes.	Tin-Lined Pipes.	Cement-Lined Pipes.	Galvanized Iron (or Steel) Pipes.	Total.
			Surface Waters.		
0 to 10	20	5	32	43	100
11 to 20	43	0	14	43	100
21 to 100	0	0	9	91	100
			Ground Water.		
0 to 10	14	0	72	14	100
11 to 20	12	12	44	32	100
21 to 50	14	3	35	48	100
51 to 100	0	0	16	84	100

It will be seen that the use of galvanized iron and steel pipe is favored for hard waters. This is natural, as hard waters do not cause iron to rust as soft waters do, and where usable, iron or steel are preferred on account of cheapness.

Lead pipe is used in 18 cities where soft surface waters are used (hardness less than 20 parts per million), but 47 cities use something else. Three cities supplied with soft ground water (hardness less than 20 parts per million) use lead service pipes, but 20 cities use something else. In round numbers, less than one quarter of the cities supplied with soft water are provided chiefly with lead services.

Tin-lined pipe and cement-lined pipe are used chiefly in the cities supplied with soft water. This is emphatically true of cities supplied with surface waters. Cement-lined pipe is also much used in cities supplied with moderately hard water, doubtless because the waters contain considerable carbonic acid.

Thus experience has taught the water-works superintendent to avoid the use of lead, iron, and steel for soft water because of corrosion, to use iron or steel for waters that are quite hard for reasons of economy, and to use cement-lined or tin-lined pipe for soft waters and waters of moderate hardness that contain carbonic acid. The theory of corrosion would have led to the same choice.

Water Hardening in England.

For many years the practice of hardening the very soft water supplies of middle England has been common. This is done by adding powdered chalk, or calcium carbonate, which unites with the dissolved free carbonic acid to form calcium bicarbonate, which is soluble.

At Sheffield, where an investigation of the prevalence of lead poisoning was made, it was recommended:

"That by way of practical experiment, a small but sufficient quantity of chalk in a minute state of division, which would not prejudicially affect the water for domestic or manufacturing purposes, be added to the water before its distribution to the town."

At a later date, after the method had been tried, it was recommended:

"That this process for treating the water with carbonate of lime in the form of chalk, or such modification as experience may show to be an improvement, be permanently continued, and that such apparatus be provided and fitted up as will permit the addition of the material to the water in an automatic manner which should be regular and continuous."

The process has been carried on as follows: *

"A measured quantity of levigated chalk, known commercially as Paris white, is placed twice a day in a small tank, oblong in plan and triangular in elevation, filled with water. A small revolving fan keeps the milky mixture continuously stirred, while a series of dredger buckets, on a chain revolving through the liquid, empties it in small constant quantities into a tank, where it is kept in motion by rotating plates. It is further diluted by a constant stream of water and discharged through a pipe below the gage basin into the main supply. The whole of the machinery is worked by a small, triple-ram water motor, the water from which is discharged into the gage basin. The weight of chalk is so regulated as to add a definite quantity varying from about 15 to 30 parts per million, according to the state of the water and its capacity for dissolving the carbonate of lime. The process is applied to the whole supply. The cost is about 52 cents per million gallons. No complaints of plumbo-solvent action have been received since its adoption."

* Notes on the Sheffield Water Supply. By L. S. M. Marsh. Proc. Inst. C. E., Vol. CLXXXI, Session 1909–10.

This method, first used in Sheffield, has been adopted in other places.

At Birmingham, where the water supply, taken from the Elan and Claerwen rivers in Wales, has a slight action on lead, Dr. Percy Frankland, F.R.S., recommended the addition of chalk to the water of the aqueduct after filtration. The works for carrying out this recommendation were designed and carried out by Mr. McCaulay,* as follows:

"A chalk-store, holding about 200 tons of chalk in bags, was erected near the west end of the filter beds, and from it chalk is carried by overhead conveyors along the filter beds to the chalking-house at their east end. There it is lifted into a hopper on the upper floor, which has a capacity sufficient for three or four days' chalking. From this hopper it is carried over a weighing machine to shutes above the four mixers already installed, two being at present in use at a time. These mixers are of the same design as those used at Sheffield except that they are without the second mixing tank."

The annual reports of Dr. J. F. Liversiege, the public analyst of the city, for the years 1905 to 1907, state that the addition of the chalk raises the hardness about 10 parts per million, the amount used being a little less than one grain per gallon. The hardness of the water as delivered to the city varies from 25 to 35 parts per million.

In 1905 Dr. Raymond Ross, of Burnlay, informed the author that chalk was added to the supply of that city to neutralize the effects of the humic acid. The hardness of the water was about 20 parts per million.

Theoretical Considerations.

There are several forms in which lime and carbonic acid may be present in water and in the air, and to avoid misunderstanding, these are briefly described.

1. Quick lime, known chemically as calcium oxide, or CaO. Placed in water, it immediately combines with it.

2. Water-slaked lime, or calcium hydrate, CaO_2H_2, or $CaO.H_2O$. This is soluble in water to the extent of 1 400 parts per million

* Proc. Inst. C. E., Vol. CLXXXI, p. 8.

(in terms of CaO) at 0° C.; 1 330 at 10°; 1 250 at 20°; 1 200 at 25°; 1 160 at 30°; 970 at 50°; and 580 at 100° C.

3. Calcium carbonate, or chalk or marble, known chemically as the normal carbonate, or $CaCO_3$, or CaO. CO_2. It is produced by the combination of CO_2 and CaO. Air slaked lime is partly this compound, as the CO_2 of the air unites with some of the CaO. The normal calcium carbonate is only slightly soluble in water, its solubility being only about 12 parts per million. The CO_2 in this combination is said to be "full bound."

4. Calcium bicarbonate, or $CaCO_3$. H_2CO_3, the ordinary form found in water. It is very soluble. It is also easily decomposed. The CO_2 can be driven off by heat, leaving the normal carbonate which will precipitate if present in amounts larger than about 13 parts per million.* Certain algæ can seize the CO_2 from the bicarbonate form and leave $CaCO_3$, which will precipitate. In this way certain marls are formed at the bottom of ponds. The CO_2 in this form is said to be "half-bound."

5. Carbonic acid is a gas and will dissolve readily in water. The amount that will remain in solution depends upon the partial pressure of CO_2 in the atmosphere over the water. (See Table 6.) In the open air this partial pressure is low, and water exposed to the open air in drops seldom contains more than 1 or 2 parts per million of free CO_2. The air in dug wells often contains a good deal of carbonic acid, so that ground waters often hold very large amounts of this gas. Animal organisms exhale it and bacteria produce it from organic matter, so that stagnant or polluted surface waters may contain relatively large amounts.

Carbonic acid has a natural affinity for calcium carbonate and in water will combine with it to form the soluble bicarbonate. In fact, waters become hard only as this action takes place, both limestone and the dissolved gas being necessary.

But carbonic acid has a stronger affinity for calcium oxide than for calcium carbonate, so that if the oxide or hydrate is added to water that contains calcium bicarbonate it will seize the extra molecule of carbonic acid, and the normal carbonate will be formed by

* The Solubility of Calcium Carbonate and of Magnesium Hydroxide and the Precipitation of these Salts with Lime Water. By G. C. Whipple and Andrew J. Mayer. Journal of Infectious Diseases, Supplement No. 2, February, 1906, p. 151.

the combination, leaving another molecule of normal carbonate unattached to CO_2, so that a double precipitation will occur. This is the basis of the well-known Clark process of water softening.

The English method of adding chalk to water neutralizes the free CO_2 and yields $CaCO_3$. H_2CO_3, which remains in solution.

TABLE 6.

SOLUBILITY OF CARBONIC ACID IN WATER.

(Compiled from Sutton's Volumetric Analysis and Fox's paper in the Transactions of the Faraday Society, September, 1909.)

Temperature, Centigrade.	CC. per Liter.* 1 part per 10 000.	Parts per Million for Stated Partial Pressures of CO_2 in the Atmosphere.			
		1 part per 10 000.	4 parts per 10 000.	6 parts per 10 000.	8 parts per 10 000.
0	.1713	.34	1.4	2.0	2.8
4	.1473	.29	1.2	1.7	2.4
8	.1283	.26	1.0	1.5	2.0
12	.1117	.22	.9	1.3	1.8
16	.0987	.19	.8	1.2	1.6
20	.0877	.17	.7	1.0	2.0
24	.0780	.15	.6	.9	1.8
28	.0780	.15	.6	.9	1.8

Substantially the same result would be reached by adding lime, but chalk in England occurs as a natural deposit and is cheaper than lime. In New England, lime would be naturally used instead of chalk for reasons of economy.

There would be this difference, however, that if an excess of lime were used, the Clark reaction would occur, that is, the end produced would be not all bicarbonate, but partly normal carbonate, and if this amounted to more than 13 parts per million, a precipitation of sludge might occur and cause trouble, just as it does in St. Louis and Columbus and elsewhere where water is softened. In what follows it is assumed that the addition of lime is only sufficient to combine with the carbonic acid present and not enough to attack the bicarbonates.

* 1 cc. of CO_2 at 0° C. and 760 mm. weighs 1.96663 mg.

Advantages and Disadvantages of Lime Treatment.

The question has arisen in the minds of some as to whether it would not be of advantage to follow the English practice and neutralize the humic acid and the free carbonic acid of the very soft waters of New England. To do so would slightly increase the hardness but would prevent danger from lead poisoning, and would make it possible to use pipes of wrought iron or steel in places where the more expensive tin-lined or cement-lined pipes are now employed. This question is not as simple as it might appear at first thought. It involves a considerati n of the entire rôle played by carbonic acid in natural waters.

The advantages of the application of lime in this way would be:

1. To prevent the danger of lead poisoning.

Theoretically, this result should be obtained, and the practical experience in England is that no trouble of this character has occurred since the application of chalk was begun.

2. To prevent corrosion and tuberculation in water mains.

With cast-iron pipes this may not be an important matter, but with steel pipes it may be important according to the amount of carbonic acid in the water and the effectiveness of the coating used on the pipes.

3. To permit the use of galvanized wrought-iron and steel service pipes under conditions where it now seems necessary to use more expensive pipes.

This would result in a saving that would partially offset the cost of the addition of the lime.

4. To prevent the red water plague.

There seems to be no doubt but that troubles with rusty hot water are less with hard waters than with soft waters and are greater in proportion to the carbonic acid present. The greatest troubles are found in very soft waters, and especially in soft waters that have been treated with alum and left with a very low carbonate hardness and a considerable amount of carbonic acid. The addition of lime in amounts sufficient to neutralize the carbonic acid normally found would at the same time slightly increase the hardness, and the combined result would be a very material reduction of rusty water troubles.

5. To lessen the need for the use of brass pipe in hot water systems.

Brass pipe is better for hot-water piping than wrought-iron or steel. It costs but little more, as smaller sizes can be used. The reason for this is that brass pipe is smoother and the friction is less, while, moreover, it does not become filled with rust. Yet in cheap building construction steel pipes are likely to be used to some extent in any event, and if the corrosive properties of the water were reduced, there would be less objection to the use of this metal. Thus the people who live in the poorer houses would be supplied with cleaner hot water.

6. To lessen the corrosion of boiler tubes and feed water heaters.

7. And in general to prolong the life of plumbing fixtures.

The possible disadvantages that might result from this treatment are:

1. The slightly increased cost of the water served. Just how much this would be, it is difficult to say. In England it is said to have cost between 50 and 60 cents per million gallons for the chalk process, but in this country the cost of adding lime would be greater, according to the facilities for applying the lime at places inconvenient of access, and whether laborers doing other work could attend to its application.

2. The slightly increased cost of soap by the water consumers.

This probably would not amount to more than five cents per capita per year.

3. The disadvantage of using a slightly harder water in the household.

This would not be a serious matter, but it is one worth careful consideration. Waters that have a hardness less than 20 parts per million do not " curdle " with soap.

4. Formation of more scale in boilers.

This would tend to offset the advantages from the lessened danger of corrosion by carbonic acid.

To these might be added certain objections of doubtful importance.

5. A slight increase in the color of surface waters stained with vegetable matter.

This would vary with the water and with the season, but the in-

crease would probably not be more than 10 per cent., and it might be less or even *nil*.

6. A slight deposition of calcium carbonate in the pipe if too much lime were used.

This would depend largely upon the amount present and the presence of organic matter.

7. Effect on the health of water consumers.

There is no reason to think that an increase of hardness from 10 to 20 parts per million would be in any way injurious to the water drinker. No element would be added to the water that is not already there. Calcium is a necessary element for human life. The hygienic advantages and disadvantages of hard and soft waters are still being discussed by physiologists with no signs of agreement. German specialists claim that the presence of lime in water improves the physique, makes stronger bones, and better teeth. On the other hand, specialists in urinary diseases believe that a hard water tends to the frequency of occurrence of calculi and other troubles of the bladder and kidneys. It is a difficult problem to solve for the reason that even in hard water regions the quantity of calcium taken into the system through the water is very small when compared with the amount present in food. The chemical combination in which it enters the body is, however, different. The scientific evidence at present must be regarded as inclusive, but experience appears to indicate that the hardness of water within the limits mentioned is a negligible hygienic factor. This subject is one that needs careful study, for our present ignorance is to be regretted.

These arguments will doutless be given different weight by different individuals. In the writer's opinion, it is by no means sure that decarbonation by the use of lime would be desirable, but in his opinion the method is well worth trying on a practical scale, and it would have to be tried on a practical scale and continued for a few years in order to determine its merits. It is a matter that cannot be decided on the basis of laboratory tests. This is the primary reason for bringing the subject before this Association.

Quantity of Lime Required.

The determination of free carbonic acid is not ordinarily made as a part of water analysis. H. W. Parker and the author * studied this subject in 1901 and collected data for various surface and ground waters under different conditions, from which it appeared that the following quantities of dissolved carbonic acid are likely to be found in New England:

	Parts per Million.
Rain water in country districts,	2 to 4
Rain water in cities,	5 to 20
Surface water supplies, at tap,	2 to 5
Surface water supplies, surface of reservoirs,	2 to 5
Surface water supplies, stagnant strata near bottom,	5 to 25
Surface water supplies, with heavy algæ growths,	0†
Streams from swamps,	5 to 15
Polluted streams,	5 to 15
Ground waters, driven wells,	2 to 40
Dug wells, well ventilated,	5 to 20
Dug wells, badly ventilated,	20 to 50

The most elaborate discussion of the occurrences of carbonic acid in lake waters is that of Birge and Juday.‡

The amounts of carbonic acid in most of the surface water supplies of Massachusetts as delivered probably do not regularly exceed 5 parts per million, though at times they may be somewhat higher. In ground waters, larger amounts are found. To neutralize one part per million of carbonic acid with lime increases the hardness 1.14 parts per million. This is the theoretical amount. Actually, the increase would be more, as commercial lime is never pure CaO. Some of it is sure to be air slaked when used, so that the figures given would have to be increased by indeterminate amounts up to 50 per cent. perhaps. Hence to neutralize the carbonic acid in ordinary surface water would theoretically increase the hardness by 3 to 6 parts per million, and in some cases by a slightly larger amount. In the case of

* On the Amount of Oxygen and Carbonic Acid in Natural Waters. By George C. Whipple and Horatio N. Parker. Transactions American Microscopical Society, Vol. XXIII, p. 103.

† Results may be negative, showing that CO_2 has been taken from the bicarbonates.

‡ The Dissolved Gases of the Water and Their Biological Significance. Bulletin XXII, Wisconsin Geological and Natural History Survey, 1911.

swampy waters, the increased hardness might be as much as 12 or 15 parts per million, and in ground waters, 25 parts per million or even more. Waters that contain more than 5 parts per million of carbonic acid may be considered as offering special problems, of which mention is made later.

TABLE 7.

INCREASE IN HARDNESS RESULTING FROM NEUTRALIZATION OF DIFFERENT THEORETICAL AMOUNTS OF CARBONIC ACID.

Free Carbonic Acid, Parts per Million.	Increased Hardness, Parts per Million.	Quantity of CaO Required, Pounds per Million Gallons.
1	1.1	5.3
2	2.3	10.6
3	3.4	15.9
4	4.5	21.2
5	5.7	26.5
6	6.8	31.8
7	8.0	37.1
8	9.1	42.4
9	10.2	47.7
10	11.4	53.0
15	17.0	79.5
20	22.8	106.0
25	28.4	133.0
30	34.1	159.0
35	39.8	186.0
40	45.5	212.0

Let us first consider the soft waters where the hardness is less than 10 parts per million and the carbonic acid about 5 parts per million. To neutralize this CO_2 would increase the hardness of the water about 6 parts per million. This would increase the amount of soap required to produce a lather by only 32 per cent., as may be seen by Table 8, upon which the determination of hardness by the soap method is based. Even distilled water requires a certain amount of soap to produce a lather. On the basis of calculation made by the writer (" Value of Pure Water," page 24) the cost of the extra soap involved by this slight hardening of the water would be 60 cents per million gallons, plus an additional allowance for air slaking of the lime.

TABLE 8.

VOLUMES OF SOAP SOLUTION REQUIRED TO PRODUCE A LATHER IN WATERS OF DIFFERENT HARDNESS.

(Committee Report on Standard Methods of Water Analysis, first edition, page 56.)

Hardness, Parts per Million.	Soap Solution Required.	Ratios of Quantities of Soap Solution Required Compared to that Required for Water of Stated Hardness.			
		Hd=0.	Hd=10.	Hd=20.	Hd=30.
0	0.70	*1.00*	0.53	0.34	0.25
5	1.02	1.46	0.77	0.50	0.36
10	1.33	1.92	*1.00*	0.65	0.48
15	1.67	2.40	1.25	0.82	0.60
20	2.04	2.82	1.53	*1.00*	0.73
25	2.43	3.47	1.83	1.19	0.82
30	2.80	4.00	2.26	1.38	*1.00*
35	3.18	4.55	2.39	1.56	1.14

The amount of lime required would be 5.3 pounds of CaO per million gallons for each part per million of CO_2. A water that contained 5 parts per million of CO_2 would, therefore, require 26.5 pounds of CaO per million gallons, or 31.2 pounds of commercial lime containing 85 per cent. available CaO. Lime containing relatively small amounts of magnesium would be needed in order not to increase this troublesome element in the water.

To apply the lime as a clear solution would require about 100 gallons of water for each pound of lime, and it would be necessary to have solution tanks in duplicate as well as mixing tanks and stirring devices. This would require daily attendance and would be somewhat troublesome in various ways. A better method would be to apply the lime, after water-slaking, by means of a dry feed apparatus. This method has recently come into successful use in mechanical filter plants. Alum is fed in this way at the filter at Springfield, Mass., and slaked lime is being fed by a dry feed apparatus at Portsmouth, Va. The dry feed is also used in St. Louis. In the quantity used the lime would readily combine with the CO_2 of the water if the dry feed were discharged directly

into the water to be treated. It would thus be possible to place an electrically operated dry feed apparatus in the gatehouse from which the main leads to the distribution system, and after charging the hopper leave the apparatus to feed automatically with very little care.

Application of Lime Before Storage.

A possible advantage of the lime treatment not mentioned above might be a tendency to check the growth of algæ in distribution reservoirs. Algæ and plants contain chlorophyll. Their growth demands sunlight and also carbonic acid. The elimination of carbonic acid would tend to prevent their multiplication. Carbonic acid is absorbed from the air by water exposed to it, up to its limit of solubility for the partial pressure of the CO_2 in the air. But carbonic acid is also produced by animal organisms and by the bacterial decomposition of organic matter. So that if the water that enters a reservoir were free from CO_2, it is not at all certain that it would remain so. It surely would not remain so for a long period. Yet it is quite possible that in distribution reservoirs, where the storage period is short, the elimination of the CO_2 from the entering water would act as a positive check to the growth of algæ and thus tend to reduce the odors that result from their growth. On the other hand, certain algæ have the power of taking their needed CO_2 from the bicarbonates. These species might be able to grow in spite of the lime treatment.

In large reservoirs where the storage is longer, the benefits of liming before storage would be less and such a preliminary application might be a mere waste, increasing the hardness without benefit.

In reservoirs where algæ at times develop to such an extent that there is a natural disappearance of the CO_2 and inroads made on the CO_2 of the bicarbonates, it would be unnecessary to apply lime.

Lime Treatment for Filtered Waters where Alum is Used.

When alum is used to produce coagulation, as in mechanical filtration, a by-product of the reaction of the sulphate of alumina on the dissolved calcium bicarbonate is carbonic acid gas, which remains in solution in the water in a condition of supersaturation until the water is exposed to the air. The amount of CO_2 added

to the water is 6.8 parts per million for each grain per gallon of alum added, or 4.8 parts per million for each 100 pounds of alum per million gallons of water. This is a very substantial increase and is the principal cause of the increase in corrosiveness of mechanically filtered water, although in the case of very soft water it is probably not the only cause. Although this production of carbonic acid has been known since the early days of the use of alum in connection with mechanical filtration, it has not been considered as a matter of sufficient importance to need correction, and as a result many unfortunate cases of the red water plague have occurred. Lately the matter has been taken more seriously, and steps have been taken to neutralize the carbonic acid by the use of lime or soda. Alum coagulated waters thus form a special case, and a very important case, of the general subject under discussion.

Use of Soda Ash.

Sodium carbonate, Na_2CO_3, known commercially as soda ash, might be and sometimes is used instead of lime to neutralize the dissolved carbonic acid. Soda is commonly used in mechanical filtration when the alkalinity of the raw water is not sufficient to decompose the alum added. Its use possesses some advantages over lime when both are applied as a solution, for soda is more readily soluble than lime and it does not increase the hardness of the water. With sodium carbonate a larger quantity of the chemical would be required than with lime. This, together with the fact that its cost per pound is greater, makes it more expensive to use. With the dry feed apparatus in use the principal advantage of soda over lime vanishes, so that in comparing the two the greater cost of soda must be compared with its advantage of not hardening the water. So far as neutralization of carbonic acid is concerned, either chemical is probably satisfactory. Whether or not soda is better than lime for use in supplying deficient alkalinity in the case of alum-treated waters has not yet been settled by chemists. There are some who think that the use of lime gives a better coagulation of the alum and a greater certainty that all of the aluminum sulphate will be changed to hydrate and precipitated, whereas with soda there is a greater possibility of

the formation of basic sulphates of alumina or aluminates, that might go through the filter and afterwards prove troublesome in the distributing pipes, and especially in hot water systems.

Aside from the question of cost, there seems to be no reason why soda might not be used for neutralizing the carbonic acid of natural waters. Indeed, some waters in nature are found to contain sodium carbonate. Thus in the eastern part of New York state many of the well waters have an alkalinity greater than the total hardness of the water.

Use of Caustic Soda. Chemically, caustic soda, NaOH, would be better than Na_2CO_3, but practically it would prove a troublesome substance to apply.

Decarbonation of Waters by Aëration.

When the amount of dissolved free carbonic acid in water exceeds 5 parts per million, its neutralization with lime would be expensive and would increase the hardness of the water by a considerable amount, but when large amounts are present it is possible to greatly reduce them by exposing the water to the air, that is, by aëration.

The quantity of CO_2 held in solution by water depends upon the amount present in the air and the opportunity that the water has of coming in contact with the air. Table 6 shows the solubility of this gas at different temperatures and for different partial pressures of the CO_2 in the atmospheres. The amounts commonly present in waters are in excess of saturation, so that if the water be exposed to the air in thin films a natural reduction of the dissolved CO_2 will occur.

In 1907 some experiments were made at the Brooklyn Polytechnic Institute by Melville C. Whipple and the author, assisted by Charles F. Breitzke, to ascertain the rate at which water would give up its dissolved carbonic acid on exposure to the air. A series of experiments was made by exposing water which contained 30 parts per million of CO_2 to the air in seven receptacles that differed in capacity and in the ratio of the exposed surface to the volume of the water. The depth of the water in these various receptacles varied from 0.2 to 100 centimeters. The experiment was made in a well-ventilated room where the atmosphere was

not greatly different from that out of doors, and the temperature did not rise above 20° or fall below 18° C. After different periods of time samples of water were withdrawn and determinations of carbonic acid made. The following figures give the approximate times required for the carbonic acid to fall from 30 to about 5 parts per million in the different receptacles:

No.	Depth in Centimeters.	Time.
1	0.2	30 minutes.
2	0.7	3 hours.
3	1.0	7 hours.
4	2.0	10 hours.
5	4.5	1 day.
6	25.0	7 days.

The various results were plotted and analyzed mathematically, and from a study of them the following generalization was drawn:

TABLE 9.

TABLE SHOWING AMOUNTS OF CARBONIC ACID REMAINING IN WATER OF DIFFERENT DEPTHS AFTER STANDING FOR DIFFERENT PERIODS OF TIME.

	Carbonic Acid in Parts per Million. Depth in Feet.			
Time of Exposure.	.01	0.1	1	10
0	30	30	30	30
10 minutes,	26	..	..	..
20 minutes,	23	..	..	..
30 minutes,	21	..	..	..
40 minutes,	19	..	..	..
50 minutes,	17	..	..	..
1 hour,	15	25	..	..
2 hours,	7	23	..	..
3 hours,	..	20	..	..
4 hours,	..	18	..	..
5 hours,	..	17	..	..
6 hours,	..	15	25	..
12 hours,	..	6	22	..
1 day,	..	..	18	26
2 days,	..	..	11	24
3 days,	..	..	5	22
4 days,	..	..	..	20
5 days,	..	..	..	18
6 days,	..	..	..	17
1 week,	..	..	..	16
2 weeks,	..	..	..	8

A second series of experiments was made by allowing water containing different amounts of carbonic acid to fall through the air in drops. This was done in the corridor of the Brooklyn Polytechnic Institute, in a well-ventilated atmosphere, the temperature being within the limits of 18° and 20° C., as before. The water was allowed to flow from an orifice 6 millimeters in diameter for different distances through the air. These distances were 1, 4, 9, 16, 5, 36, 49, and 64 ft., which correspond to quarter-second divisions of time from a quarter of a second to two seconds.

It was found that the stream from the orifice began to break into drops after 0.18 second. At first the drops remained rather close together, but after a fall of one minute the individual drops spread over a circle about 9 in. in diameter, and after two minutes the diameter of this circle had increased to about five feet. Some experiments on the drops showed that the surface of the water exposed to the air was about 12 000 square centimeters for one liter of water. The falling water was caught after the given periods of time and determinations of carbonic acid immediately made. The results were then plotted on logarithmic cross-section paper, with the times as abscissæ and the amount of carbonic acid as ordinates, and it was found that the points fell on straight lines, as theoretically they should do. Some mathematical analyses were made of these results, and from them Table 10 was prepared, showing the reduction of the carbonic acid in the air obtained by allowing the water to fall through the air in drops for different periods of time.

Various series of experiments were made at different temperatures, which showed that, generally speaking, the loss of carbonic acid from water exposed to the air in drops would be 50 per cent. more in summer than in winter. Experiments also showed that the loss of carbonic acid depended upon the time of exposure rather than upon the distance through which the drops fell.

No great degree of scientific accuracy is claimed for these experiments, and the results would have been slightly different if the experiments had been made out of doors, but they showed in a general way that falling drops of water supersaturated with CO_2 require about fifteen seconds to discharge this excess CO_2

TABLE 10.

TABLE SHOWING REDUCTION OF CO_2 OBTAINED BY ALLOWING WATER TO FALL THROUGH THE AIR IN DROPS FOR DIFFERENT PERIODS OF TIME AT 20° C.

Time in Seconds.	Carbon Dioxide, Parts per Million.								
0.18	5.0	10.0	15.0	20.0	25.0	30.0	40.0	50.0	60.0
0.25	4.7	8.9	12.8	16.8	20.6	24.2	32.0	39.0	46.5
0.50	4.1	6.9	9.3	11.7	13.8	15.8	20.0	23.4	27.0
0.75	3.7	5.9	7.8	9.4	10.9	12.3	15.0	17.4	19.8
1.00	3.5	5.3	6.8	8.1	9.3	10.3	12.4	14.0	15.8
1.25	3.4	4.9	6.2	7.2	8.2	9.0	10.6	12.0	13.2
1.50	3.2	4.6	5.7	6.5	7.3	8.0	9.4	10.5	11.5
1.75	3.1	4.3	5.2	6.0	6.7	7.3	8.5	9.3	10.2
2.00	3.0	4.1	5.0	5.6	6.2	6.7	7.7	8.5	9.2
2.5	2.9	3.8	4.5	5.0	5.5	5.8	6.6	7.2	7.7
3.0	2.8	3.5	4.1	4.6	4.9	5.2	5.8	6.3	6.7
3.5	2.7	3.5	3.8	4.2	4.5	4.7	5.2	5.6	6.0
4.0	2.6	3 2	3.6	3.9	4.2	4.4	4.8	5.1	5.4
10.0	2.2	2.2	2.3	2.3	2.4	2.5	2.6	2.7	2.8
15.0	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.1

into the atmosphere. An exposure of two seconds during warm weather ought to reduce the amount of CO_2 from 25 to 30 parts per million to 5 or 6 parts per million. This is about the limit that can be obtained in practice by aëration in fountains and sprays.

It would be possible to combine aëration by fountains or sprays with the use of lime or soda, utilizing aëration to remove the greater part of the CO_2 and neutralizing the small amount left by chemical means. The alternative proposition would be to prolong the exposure of the water to the air, reducing the CO_2 to the amount required to saturate it. This would not remove all of the CO_2, but the quantity left would be small. This prolonged exposure could be obtained by allowing the water to fall through holes in a series of trays placed one above the other, or to trickle through beds of broken stone or other coarse porous beds, as is done in Germany in connection with the iron removal process. If this were done, adequate ventilation would be all-important, for if the partial pressure of the CO_2 in the air of the bed or between

the trays were increased, the solubility of the gas would be raised and the CO_2 would not leave the water. Weston has described some of these aërators in his paper on the Purification of Ground Waters, published in the Transactions of the American Society of Civil Engineers, Vol. LXIV, page 114.

Conclusions.

On account of the many unknown factors involved in this problem, the author presents this paper without definite conclusions or recommendations, trusting that it may be the subject of an extended discussion and lead to further investigations of some of the doubtful matters, and to a practical trial in some city where the corrosion problem is serious enough to warrant it.

If the problem of corrosion is to be satisfactorily solved it must be approached from two directions, — from a consideration of the metals used and the character of the water itself. The burden of furnishing pipes of good quality rests upon the manufacturers of supplies, but is there not also a burden that rests upon the water-works authorities, namely, that of reducing the corrosive character of the water where this can be done without undue expense and where the sum total of the advantages might more than equal the disadvantages of the required treatment?

Discussion.

John C. Thresh, M.D. (*by letter*).* Although a considerable amount of attention has been given to this subject in England, it has never assumed the importance which appears to be the case in many parts of the United States. In the north and midlands counties surface water supplies are largely used, but very often there are springs on the collecting areas containing sufficient carbonates of calcium and magnesium to neutralize the plumbo-solvency of the surface water. Where this is not the case, decarbonation is attempted. At first, attempts were made to decarbonate by allowing the water to run through channels containing broken chalk. This proved unsuccessful since the chalk soon became covered with a slimy growth of bacteria

* London Hospital, London, England.

which inhibited the solvent action of the carbonic acid in the water. Filtration through beds of limestone was next attempted, but this material also became slimy, and to prevent this the limestone was placed under a bed of sand. This was an undoubted improvement, but experience has shown that it is unreliable. The Candy Filter Company use magnesite, native $MgCO_3$, which is packed in mechanical pressure filters, and the frequent washing appears to keep this clean and active. The plan usually adopted, however, is the addition by means of a mechanical mixer of powdered chalk or whiting, as this gives the most reliable results. Nearly every works has a different kind of mixer; some add the chalk in powder, others in the form of "milk of chalk." They are equally efficient. The chalk deposited at water works when water is softened by Clake's process can be used, but usually the works using waters of such different types are too far apart to render this practicable.

In other parts of England there are waters, chiefly derived from deposits of non-calcareous sands, which markedly act on metal pipes, and the addition of chalk has very little effect. These waters usually contain a little magnesium chloride, and to this constituent I am inclined to attribute the effect. In these cases I have recommended the addition of about two grains of sodium carbonate to each gallon of water.

If properly coated pipes are utilized, no trouble may arise from the use of such a water. If imperfectly or improperly coated mains are used, then trouble arises, as in the following case.

The village of Tiptree in Essex is supplied with water taken from gravel beds, and this had been used for years without giving rise to complaint, save from one person who had laid a long service pipe of galvanized iron, and the water dissolved marked quantities of zinc. Recently the mains were extended to a place named Tudwick, and when completed complaints were received along the routes of the extended mains about the turbidity of the water. A somewhat lengthy special report was prepared on this subject which showed that the water from the old mains was always bright, but that all samples taken from the three recent extensions were always more or less turbid, either when drawn or within a few minutes afterwards. The worst samples were always from the

Tudwick main, which is 2 600 yards long and has no house connection for a distance of 2 000 yards. The water might be merely tinted brown and be fairly clear when drawn, but upon exposure to the air it speedily began to deposit oxide of iron, and in a few hours there would be a marked brick-red sediment at the bottom of the containing vessel. The Tudwick branch pipe is not coated with the ordinary black varnish but with some kind of paint, but the other branches complained of are coated in the usual manner. I obtained samples of these latter, 2-in., 3-in., and 4-in. in diameter, and having plugged one end I allowed them to stand full of water for twenty-four hours. In no case did the water take up more than the most minute trace of iron, and the samples remained perfectly bright afterwards. When, however, patches of the varnish inside were scraped off, the water dissolved marked quantities of iron, and became turbid afterwards when exposed to air. There can be no doubt that in these branch mains the pipes are not thoroughly coated, hence the action of the water.

The analysis of this water shows it to contain in each gallon:

Calcium carbonate	3.5 grains.
Calcium sulphate	1.9 ,,
Magnesium sulphate	.7 ,,
Magnesium chloride	.6 ,,
Sodium chloride	1.7 ,,
Sodium nitrate	2.7 ,,
Silica, etc.	.4 ,,
Total	11.5

There is nothing here, unless it is the trace of magnesium chloride, to indicate that the water would have any special effect upon metals.

We experience far more trouble with hard waters than with soft waters in Southern England, hence the question of "softening" is much more interesting than that of "decarbonating."

It may be interesting to compare Professor Whipple's table of the hardness of Massachusetts supplies with those of the county in which I am most interested, Essex, with its population of about one and one-half millions.

HARDNESS OF WATER USED IN THE URBAN AND RURAL DISTRICTS OF ESSEX, HAVING WATER SUPPLIES DELIVERED FROM MAINS.

Name of Authority or Water Company.	Source of Water.	Hardness, Parts per Million.
Braintree, urban	Deep well.	160
Braintree, rural	Deep well.	200
Brightlingsea, urban	Deep well.	170
Chelmsford, borough (*a*)	Springs.	320
(*b*)	Mixed spring and deep well.	130
Chelmsford, rural	Deep wells.	40 to 50
	Springs.	100 to 380
Clacton-on-Sea, urban	Springs.	160
Colchester, borough	Deep wells and springs.	160
Dunmow, rural	Springs.	400
	Deep well.	340
Halstead	Deep wells.	270
Herts and Essex Water Company	Deep wells.	300
Metropolitan Water Board	Deep wells and river.	220 to 320
Malden, borough	Deep wells.	75
Malden, rural	Springs.	100
Rochford, rural	Deep wells.	40
Saffron Walden, borough	Deep wells before softening.	370
Saffron Walden, borough	Deep wells after softening.	120
Shoeburyness, urban	Deep wells.	40
Southern Water Company's wells	Deep wells (22).	28 to 700 Average about 80
South Essex Water Company's wells	Deep wells.	125 to 240
Stanstead, urban	Deep wells.	300
Tendring Hundred Water Company's area	Deep wells.	210
Witham, urban	Deep wells.	100
Wyrenhoe, urban	Deep wells.	150

In my annual report on the County of Essex for the year 1910, I made a somewhat detailed study of the mortality statistics of the soft water areas (hardness under 100 degrees), of the moderately hard water areas (hardness between 100 degrees and 200 degrees), and the hard water areas (hardness over 200 degrees), and I present the briefest possible summary for what it is worth.

DEATHS PER 1,000 POPULATION.

	From All Causes.	From Cancer.	From Phthisis.
Soft water areas	10.2	1.07	.84
Moderately hard water areas	11.7	.86	.93
Hard water areas	10.2	.73	.93

The use of lime for removing free carbonic acid has invariably proved unsatisfactory, and I know of no place where it is employed. I have experimented with it for preventing the action of certain waters on lead, but the results were most disappointing. It is well known that when used for softening water a large number of bacteria are precipitated with the calcium carbonate, and remarkably purifying effects have been obtained at works under my control when the water from deep wells had become polluted. To obtain uniformly satisfactory results, filtration had to be discarded, and the water allowed to clarify entirely by subsidence. When this was done a water corresponding to most efficiently slow sand filtered water was produced continuously.

Decarbonation of water is also practiced here for the removal of iron from waters in which it appears to exist as a ferrous bicarbonate. Exposure to air by flowing in cascade is not always sufficient, but the addition of a little chalk or lime prior to aëration causes the removal of all the iron. The removal of the last trace of carbonic acid is exceedingly difficult, and I was never able to accomplish it when carrying out experiments on the action of distilled water on lead.

Professor Whipple does not refer to the waters which do not dissolve lead yet erode it. This erosive action appears to be due to the presence of oxygen, and the solvent action to the presence of oxygen and carbonic acid. When a sufficient quantity of carbonates is present apparently a very insoluble oxy-carbonate of lead is formed which may entirely prevent the action of the free carbonic acid unless present in an unusual amount. If the water does not contain the requisite quantity of carbonates and very little carbonic acid, the lead becomes coated with an easily removable film of oxy-hydrate of lead; that is, "erosion" takes place. If a sufficiency of carbonic acid is present, the lead enters solution and the water has a "solvent" action.

It follows, therefore, that a water may be decarbonated and yet have an action upon lead pipes. Such a water when placed in a shallow Petri dish in such volume as just to cover a piece of bright lead will show an erosive action in a very short time; whereas if placed in a deep, narrow tube with the piece of lead several inches beneath the surface the erosion may be so slight, even after twenty-four hours, as to be barely discernible. The effect appears to depend upon the amount of oxygen dissolved in the water. Are these erosive waters dangerous if passed through lead service pipes? I should like the opinion of any persons who may have had experience with such waters. So far as my experience extends, they are not dangerous. Possibly the interior of the pipe, being free from air, becomes coated with an insoluble deposit which prevents any further action of the water.

MR. E. E. LOCHRIDGE (*by letter*).* Mr. Whipple has presented much information in this paper, and while it will undoubtedly be surprising to many that a water of a high degree of purity can be so troublesome, nevertheless, with the further knowledge which is bound to come in this matter, it will soon be an accepted fact that the soft waters of this region have a certain corrosive quality which is troublesome with some kinds of pipe.

Since the trouble experienced with red water in some parts of Springfield, I have taken every opportunity to note the conditions in other cities with natural water supplies which are probably of about equal hardness. I find that the red water trouble in many of these places is fully as pronounced, and in many cases more so, than was the case in Springfield. The water supply, however, being a natural supply and subject to the variations of color, etc., of such a supply, do not give occasion for comment on the higher colored hot waters that is the case when a filtered water is produced of substantially uniform quality throughout the year.

The public is becoming more critical on the question of the quality and appearance of water furnished from public supplies, and as filters and other means of purification are extended, this question will become more and more pertinent. If anything can be done to relieve the situation as is suggested by Mr. Whipple it

* Chief Engineer, Springfield Water Department, Springfield, Mass.

is well worth studying, but in the meantime, it would seem to me that water-works people should encourage the use of such pipes as will give a uniformly high grade of service for both hot and cold water, and this can be done with little additional cost at the present time.

INSULATION OF JOINTS IN PIPE LINES.

BY WILLIAM R. CONARD, INSPECTING ENGINEER, BURLINGTON, N. J.

[*Read February 12, 1913.*]

Some years ago it was my privilege to get pipe for carrying high-pressure gas, or rather that was the term used in speaking of it, and the thought was that it might be of interest to the New England Water Works Association to have a short description of the manner in which these pipes were laid in an endeavor to get a line as nearly proof against electrolytic action as possible.

The pipe were purchased and laid by the Meriden Gas Light Company from their Meriden plant to Southington and Cheshire, Conn., in all about 15 miles of 6-in. pipe.

The pipe were of the ordinary bell and spigot type with the bell made 5 in. deep and with no lead groove (see Fig. 1), and were tested to 50 lb. of air per sq. in. at the foundry in addition to the regular hydrostatic test.

In laying these pipe the joints were made up by placing at the base of the bell $\frac{1}{4}$-in. wooden ring, oil-soaked; the spigot of the pipe next to be used was then encircled with a rubber band about $\frac{1}{16}$ in. thick and $2\frac{1}{2}$ in. wide placed about $5\frac{1}{2}$ in. from the spigot end of the pipe to prevent an iron ring, afterwards put on, coming in contact with the pipe; the pipes were then put together, the spigot going home against the wooden ring, and about $1\frac{1}{2}$ in. of untarred jute packing calked tight; instead of lead being poured in to make the rest of the joint, an insulating compound about 3 in. deep, black in appearance, which melts readily at 200° F., was poured, after which a square rubber packing was put on, and then a No. $4\frac{1}{2}$ Dresser coupling was applied to the joint and clamped tight (see Fig. 2).

To those unfamiliar with the Dresser coupling, I would say that it consists of two split clamp rings; one split clamp ring fitting around the outside of the base of the bell, the other around the outside of the spigot end of the pipe, entering the bell, with a 1-in. square rubber packing ring between it and the bell. The two

rings are connected and drawn towards one another by four bolts, one ring pressing against the square rubber packing.

The line, after laying and in sections, was tested with 20 lb. per sq. in. air pressure, and all joints found tight.

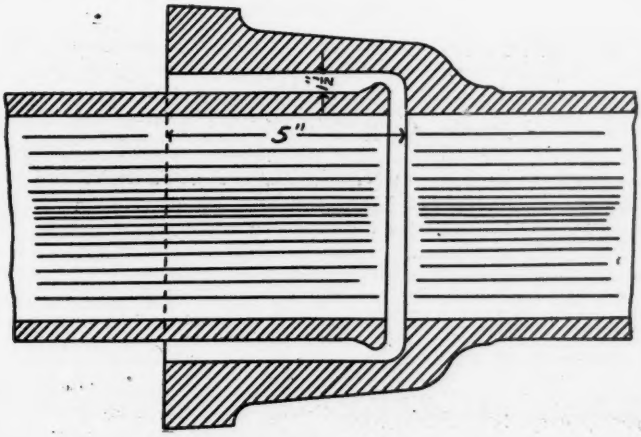


FIG. 1.

CROSS-SECTION OF BELL AND SPIGOT.

Joints made up in this manner are as flexible as poured lead joints, acting just as readily as expansion joints, and electric tests made shortly after installation indicated no flow of electricity at all, although, the entire pipe line parallels an electric car line.

The expense of a line like this figured about three times greater than for an ordinary lead joint, but for a gas line it was considered very desirable that it should be no conductor of electricity.

It is probably true that the rubber used in these joints will in time disintegrate, but it is also true that it will last for quite a number of years, for the moisture in the earth and the absence of exposure to the atmosphere should keep the volatile particles of the rubber alive for a long while.

As an insulated joint to prevent pipe lines from carrying stray currents of electricity it would appear that it would be fully as serviceable for water as for gas lines.

On the line to Southington these insulated joints were installed on every other pipe, and on the line to Cheshire on every joint.

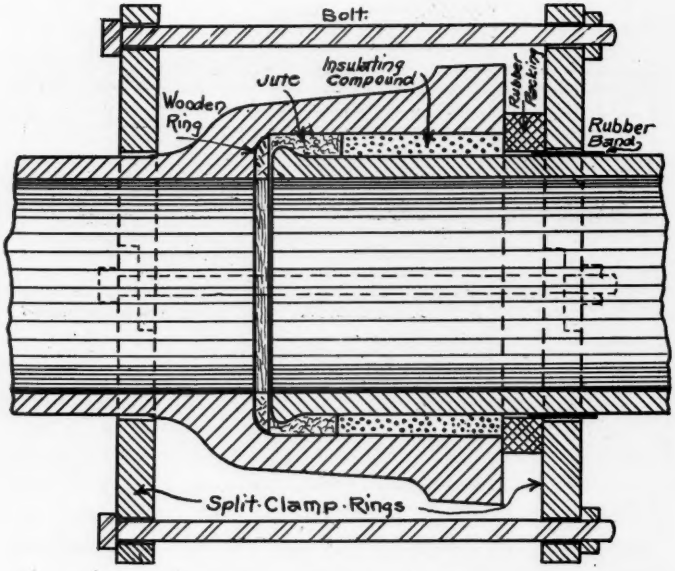


FIG. 2.

THE JOINT MADE UP.

Since writing the above I learn from Mr. Brackett, chief engineer of the Metropolitan Water Works, that rubber insulated joints have been used by them and were successful when installed, but due to some cause not definitely determined, though thought to be due to a large amount of current charging the pipe from a heavy electric storm, the rubber was in part carbonized and thereby became a conductor rather than an insulator. It would appear, therefore, that so long as electricity can be prevented

from collecting in large volume, the joint described is an efficient insulator, but one can never tell what is going to happen during an electric storm. If the rubber once becomes carbonized or loses volatile properties, it fails as an insulator.

DISCUSSION.

MR. RICHARD D. CHASE.* It seems to me that this joint, so far as the filling of the space between the hub and spigot, is well adapted to the purpose. However, if I read the drawing aright, there is nothing but a thin layer of rubber underneath the clamp in front of the hub to prevent a current of electricity from passing from the pipe back of the hub through the clamps and bolts and again into the pipe. Dependence is placed on a piece of rubber apparently about an eighth of an inch thick, which would be very likely to disintegrate. If some way could be found of insulating the bolts from the clamps, I should think the joint would be very much better. It might be possible to insert in the bolt-holes a porcelain thimble so as to break the connection around the hub.

MR. LEONARD METCALF.† The statement in regard to the experience with the carbonizing of the rubber is interesting, especially in view of the fact that rubber joints have been used abroad in suction pipe lines to a very considerable extent and very effectively, I believe, and, so far as I have chanced to hear, they have not given any trouble of that sort. I think such joints have been used abroad certainly for periods of upwards of ten years. Of course a very pure grade of rubber is required.

MR. CHASE. In the case Mr. Metcalf mentions, the rubber would be inside the hub?

MR. METCALF. It would.

MR. CHASE. If so, it would be somewhat protected. In this particular joint it seems to me that reliance is placed entirely on a thin sheet between the clamp and the pipe, where it would be exposed to decay.

MR. METCALF. I think Mr. Chase's point is a good one. That could be obviated, however, by making the casting which rests

*New Bedford, Mass.
†Of Metcalf & Eddy, Consulting Engineers, Boston, Mass.

over the bell cup-shaped, so it would come down and close over the metal of the bell.

MR. ROBERT S. WESTON.* The rubber joints, as used abroad, consist simply of a ring of very pure rubber, and are squeezed into the joint by putting the rubber ring over the spigot and rolling it into the bell. Rubber, as you know, absorbs about 25 per cent. of its weight of oxygen, and becomes hard and brittle. But if it be kept away from the air and immersed in water it ought to last indefinitely. We have kept rubber tubing in the laboratory in water without any deterioration for several years. I think the practice abroad is to use these joints almost entirely on their suction lines. They drive the pipe home and then cover the rubber ring with moist clay.

*Consulting Sanitary Engineer, Boston, Mass.

QUANTITATIVE ESTIMATION OF GROUND WATERS FOR PUBLIC SUPPLIES.

BY MYRON L. FULLER, CONSULTING ENGINEER, BOSTON, MASS., FORMERLY IN CHARGE OF GROUND WATER INVESTIGATIONS IN THE EASTERN UNITED STATES FOR THE UNITED STATES GEOLOGICAL SURVEY.

[*Read March 12, 1913.*]

EXISTING CONDITIONS.

The development of water supplies from surface sources has long received the careful consideration of hundreds of engineers, including many of the most prominent in the country. The questions involved have been earnestly attacked, thoughtfully considered, carefully weighed, and painstakingly solved, not only for the large cities, but for the smaller municipalities, towns, and villages as well. The best thought of our best men has been freely given to the subject.

Ground-water supplies, on the other hand, with a few exceptions, such as the Long Island supply, investigated by the New York Commission on Additional Water Supply, have rarely received, here in the East, more than the passing attention of engineers. The problems, lying, as they do, outside the usual limits of the engineer's training and experience, have seldom been studied with anything like the same degree of thoroughness as the surface supplies. Too often, he has assumed, because they have been obscure to him, that the occurrence and movements of ground waters follow no definite laws, and that the securing of adequate supplies is, in most cases, a mere matter of luck.

In reality, the principles controlling the collection, absorption, storage, motions, and recovery of the waters within the ground are as definite as those governing the waters upon the surface, and are worthy of the same serious consideration that has been given to the latter. If this is given them, their problems are equally open to solution, and the prediction of supplies will become a matter of comparative certainty rather than of mere conjecture.

It should be emphasized, however, that the problems fall only in part within the province of engineering. The greater part, on the contrary, are geological and require a degree of training and experience found, as a rule, only in the specialist.

Conservation and efficiency are the watchwords of the day, and nowhere is there more opportunity for their successful application, or more room for their development, than in the utilization of ground waters for public supplies. At the present time, municipalities as well as corporations are to an alarming extent groping in the dark in the search for such supplies. I believe that, taking New England as a whole, not less than 25 per cent. of the expenditures for wells is wasted through injudicious location of wells, improper methods of sinking, and unnecessary depth of drilling. In many localities the waste rises higher, and occasionally the entire outlay is a total loss. When it is remembered that the wells sunk each year are numbered by hundreds, the heavy loss involved even by a 25 per cent. waste will be appreciated.

It is the purpose of this paper to outline briefly what has been established as to the water-bearing capacities of various rocks and unconsolidated materials, and to indicate the principal steps necessary in quantitatively estimating the ground waters available for public or other supplies.

BASIS OF QUANTITATIVE ESTIMATION OF GROUND WATERS.

The basis for the following statements and conclusions concerning the quantitative determination of ground waters is the work of the United States Geological Survey, on which organization the author had for some years the direction of the ground-water investigations in twenty-seven of the eastern states, supplemented by later experience in connection with consulting work for San Francisco and other cities and corporations.

For many years, the Geological Survey has had a considerable number of parties constantly in the field during the working season, and has accumulated and published a large quantity of valuable data on ground waters in all parts of the country and in all classes of materials.

Among the most important data from the standpoint of the members of the New England Water Works Association are those pertaining to the quantitative occurrence of water in the numerous types of sedimentary or glacial deposits, or in the many different varieties of rocks. The government investigations of these problems have, in many instances, been "type studies," and although often based on conditions in areas of comparatively limited extent, are, nevertheless, susceptible of general application to materials of the classes investigated wherever they may be encountered.

For example, the results of the Long Island investigations by the New York Commission and the United States Geological Survey may be regarded as standards of information for glacial sand-plains throughout the country. The government's conclusions concerning the granites of Connecticut are equally applicable to most of those of Massachusetts, Maine, New Hampshire, or Vermont. The investigations of the limestones of Ohio, the slates of Maine, the sandstones of the West, and the glacial drift throughout the East are likewise applicable to similar deposits wherever they may be found. It is through such studies that we are able to undertake the quantitative estimation of ground waters with a reasonable degree of confidence.

FACTORS IN GROUND-WATER ESTIMATES.

In any attempt to estimate available ground waters, a certain number of factors common to all localities must be carefully considered if the deductions are to be of value. These may be stated as follows:

1. Nature of water-bearing materials.
2. Storage capacities of water-bearing formations.
3. Availability of supply.
4. Area tributary to wells.
5. Velocity of underflow.
6. Rate of replenishment.

Those of you who are familiar with well drilling will, I feel sure, agree with me that in the vast majority of cases the

knowledge of the foregoing factors is practically confined to the first. In not more than one out of ten wells is there an *adequate* knowledge of storage capacity, rate of yield, or tributary area, while in hardly one in a thousand is the velocity or rate of replenishment seriously investigated.

All the factors enumerated are, nevertheless, susceptible of approximate determinations and, when known, greatly restrict the range of errors of estimation.

DETERMINATION OF WATER-BEARING MATERIALS.

The determination of the character of materials to be encountered in a well is not so simple as might appear. In many instances the immediate surface affords but little indication of what lies beneath. The glacial deposits which overlie the rock practically everywhere in New England are highly variable in character and may range from loose sand to dense hardpan within an interval of a few feet. The depth or thickness of such deposits is likewise subject to abrupt changes within short distances.

The character of the solid rock lying beneath the surface deposits is, in many instances, even more difficult to determine, for although some formations are of nearly uniform character over wide areas, others change rapidly from point to point. In a large number of cases the changes occur beneath valleys where the rock is deeply buried.

The determination of the character of the rocks at considerable depths below the surface is seldom an impossible task. On the contrary, it may usually be made with a reasonable degree of accuracy. But the work is properly that of the geologist, and the judgment of the layman or of the average driller or engineer, unless he has had extended experience with geological problems, will ordinarily be of little value if the conditions are at all complicated. Too often he does not even know whether they are complicated or not.

The importance of an accurate determination of the character of the water-bearing materials will be apparent to all, for upon it will depend the storage, the rate of yield, and the quality of the supply. There can be no question that the best information

obtainable should be secured before drilling is begun if the work is to be conducted in the most intelligent and economical manner.

STORAGE CAPACITIES OF WATER-BEARING FORMATIONS.

The volume of the ground-water depends directly upon the containing material, and if a quantitative estimate is to be made, the nature of the water-bearing bed must be accurately known, for upon it depends the character of the storage, — whether in pores, in joints or fissures, in cleavage or schistosity plains, in solution passages or cavities, etc.

Here again an intimate knowledge of the occurrence of ground waters is indispensable. Every one knows that open cavities are encountered in rocks, but comparatively few realize that such openings are found only in limestones, and that in our granites, sandstones, and slates there is not the remotest possibility of encountering such a passage.* All of you know that water is found in the joints or fissures of granites, but how many are there who appreciate that the width of these is seldom more than a twentieth and is often less than a fiftieth of an inch, and that few of them extend more than a few hundred feet, thus cutting off the possibility of a distant supply. Yet these and other similar factors are of vital importance in the estimation of the yield of proposed wells.

AVAILABILITY OF SUPPLY.

The availability of ground waters, or the quantity yielded to wells, has no relation, strange as it may seem, to the storage capacity of the materials in which they occur. Often the formations containing the largest supplies will yield the least. In the following table, the first column indicates the volume of water actually contained in rocks and soils of various types, while the second shows the usual yield (or available supply) from the pores.

* The supposed openings in the latter rocks, assumed to exist because of the sudden dropping of the tools while drilling, are in reality simply soft streaks, often of a cheese-like consistency, consisting of clayey products of decomposition known as selvage through which the drill penetrates at a single stroke. They are the result of the circulation of water within the rock, and will, therefore, naturally afford considerable water to wells.

TABLE 1.

POROSITIES AND YIELD OF ROCKS AND UNCONSOLIDATED MATERIALS.

Material.	Storage Capacity or Porosity. Per Cent. of Volume.	Normal Yield to Drilled Wells from Pores.* Per Cent. of Volume.
Quartzites (average)	½	None
Granites (average)	1	None
Slate and shale (average)	4	None
Limestone and marbles (average)	5	None
Sandstones	5 to 25	1 to 15
Gravel (mixed with sand)	20 to 30	10 to 20
Sand (medium to coarse)	30 to 40	10 to 25
Sand (fine)	30 to 40	5 to 20
Clay	40 to 70	None
Till or bowlder-clay	20 to 60	0 to 20

The table does not, by any means, tell the whole story. For instance, while clays will yield practically nothing to wells, they are of great value as feeders to underlying rocks, to which they slowly give up their water. In many instances, as at Boston, the capacities of rock wells are probably doubled by the presence of their clay covering. Again, while the sandstones may show an ultimate yield of from 1 to 15 per cent. of their total supplies, the water often enters a well too slowly to be of value as a source of supply.

In fact, there are so many modifying conditions that the determination of the probable quantity of a proposed supply demands a thorough knowledge of ground waters and a careful study of local conditions.

AREA TRIBUTARY TO WELLS.

It hardly needs to be called to your attention that the ultimate quantity to be derived from wells at a given point will be, other things being equal, proportional to the extent of the tributary area. It is not always, however, a simple matter to determine the distance from which water will find its way to a well, and a separate determination, based on a careful examination, must be made at each locality. There are, however, certain general

* The figures in this column do not include the yield from fissures, joints, or cleavage planes. Water remaining in rock is largely residual moisture held by capillarity.

facts regarding the distances traversed by ground waters which should be of interest to members of this Association. Some of these are summarized below.

TABLE 2.

DISTANCES TRAVERSED BY GROUND WATERS.

Material.	Usual Distance of Source from Well.	Ordinary Maximum Limit of Transmission in United States.
Surface sands and gravels	Less than 1 mile.	25 miles.
Deep sands and gravels (beneath clay or other confining layers)	Several miles.	100 to 200 miles.
Sandstones near surface	½ to 1 mile.	5 to 10 miles.
Deeper sandstones	Several miles.	100 to 300 miles.
Limestones near surface	½ to 1 mile.	10 to 20 miles.
Deeper limestones	Several miles.	100 to 200 miles.
Slate or shale near surface	Less than 500 ft.	Rarely over 1 mile.
Deeper slates or shales	Possibly several miles.	Rarely over 10 miles.
Granites	Less than 1 000 ft.	Rarely over 2 or 3 miles.

NOTE. — Some rocks are water-bearing at greater distances from the outcrop than is indicated in the table, but it seems probable that the water has been absorbed by capillarity from overlying materials rather than derived by transmission from remote catchment areas.

The wide variations in the areas tributary to different sets of wells will be appreciated from an examination of the foregoing table. The problems of source and tributary area are, naturally, geological in their nature and will require the services of a geologist for their solution. To one trained in this line, however, they will ordinarily present few difficulties.

THE VELOCITY OF UNDERFLOW.

As in the case of a surface stream, the quantity of available ground water at a given point is determined by multiplying the cross-section of the moving water body by the velocity of its movement. This will give us the normal underflow, or, in other words, the maximum available supply; for, although it is possible to pump for a time from the reservoir (accumulated storage) within the ground, no more water can be obtained in the long run than is normally flowing within the limits of the area tributary to the wells.

Only in a very few cases has the velocity of underflow been determined in connection with the development of municipal supplies, although it is perfectly practicable where the water occurs in unconsolidated material of reasonable uniformity, and would undoubtedly prevent the waste of large sums in injudicious prospecting or unwarranted development.

The most successful process of measuring underflow is the Slichter method, described on page 268. It can be applied by any mechanical or other engineer, but for the interpretation of results, and more especially the determination of the extent of the tributary area, usually demands considerable geological knowledge and experience.

RATE OF REPLENISHMENT.

An accurate determination of the rate of replenishment is of the first importance, for, no matter how great the storage and how large the tributary area, a large permanent supply will be obtainable only when the average absorption is at least equal to the quantity of water withdrawn.

In New England, the determination of the rate of replenishment is a comparatively easy matter, for we are here dealing with an area of abundant and well-distributed rainfall, relatively low evaporation, and fairly simple absorptive conditions. In the western arid and semi-arid regions, on the other hand, the problems are more complex. There, the rainfall and evaporation are very irregular and it takes but little to disturb the balance and change a net gain to a net loss. When the loss by evaporation becomes greater than the rainfall, the replenishment can take place only by absorption of water from the streams, which often pour down more or less transient floods after heavy rainfalls. In such instances, careful field observations, supplemented by laboratory tests to determine porosities and rates of percolation, are necessary to determine the rate of absorption and additions to the ground-water reservoir.

In the East, the problem requires a careful computation of the rainfall and an analysis of its seasonal distribution, together with a similar investigation of seasonal evaporation and plant

transpiration, and an accurate determination of the porosity, size of grain, rate of percolation, nature of vegetation, and other minor factors regulating absorption.

LIMITED VALUE OF TEST WELLS AND PUMPING TESTS.

Water-works men and engineers have frequently remarked to me that, after all, the only way to tell whether or not one has a supply is to put down a test well and make a pumping test.

With this view, I do not at all concur, for it may be readily shown that pumping tests come far from furnishing complete data as to the availability of permanent supplies. What a pumping test shows and what it does not show is concisely summarized the following table.

TABLE 3.

DATA FROM PUMPING TESTS.

Pumping tests *show*	Pumping tests *do not show*
1. Character of material at well.	1. Average character of material of tributary area.
2. Presence or absence of water at time of test.	2. Permanency of the supply.
3. Rate of delivery when water is at maximum height.	3. Rate of delivery from depleted reservoir.
4. Quality of water at start.	4. Quality of water after continued pumping.
	5. Direction of movement of ground water.
	6. Velocity of ground-water movement.
	7. Source of water.
	8. Extent of tributary area.
	9. Rate of replenishment.

That a knowledge of the materials at the well is insufficient is indicated by the fact, long known to ground-water engineers, that it is the average section for the whole area and not its character at a single point that determines both storage and movement of the ground water. This is manifestly not furnished by a single test well.

The pump may deliver during a test very large volumes of water, but, except where the supply is very limited, and hence

readily depleted, the test shows nothing as to the supply permanently available. Many wells tap ground-water reservoirs containing the accumulated supplies of long periods, but the fact that half a million gallons may be withdrawn daily for a few days is no indication that the permanent yield, taking it year in and year out, will be more than a small fraction of this amount.

When the water table stands high in the ground, the entrance of the water into a well is relatively rapid, but the rate of entrance declines as the water table becomes lowered through depletion. The extent to which the supply will be affected can be determined only by a study of the tributary area, velocity of underflow, and rate of replenishment, no indications of which are afforded by pumping tests.

It is well known that in heavily pumped wells the quality of the ground-water supply often deteriorates with the passage of time, although possibly not for some months or years, but the nature and extent of the change is to be predicted from a study of the character of the materials and of the geological structure rather than from a necessarily brief pumping test.

The direction of movement of the ground waters is of considerable moment in determining the liability of pollution by contaminating matter from the surface, or of the likelihood of the penetration of sea water or other mineralized waters from clays, shales, bog iron ores, peats, etc., but is not usually indicated by the pumping test.

The paramount importance of a thorough knowledge of the rate of underflow, the source of the supply, the area tributary to the wells, and the rate of replenishment has been already indicated. Without such knowledge, there can be no clear conception of the problem, and the search for a supply will be mere guesswork. That the information is not to be gathered from the results of pumping tests will, the author thinks, be conceded by all.

Notwithstanding the limitations of the data furnished by pumping tests, I do not wish to be understood as maintaining that such tests are without value. On the contrary, they are of much value when their limitations are understood. They should, however, be regarded as adjuncts to ground-water investigations rather than as final in themselves.

QUANTITATIVE ESTIMATION OF GROUND WATERS.

Having touched upon some of the more important general problems involved in the determination of available ground waters, the estimation of the prospective supplies to be secured from the various rocks and unconsolidated deposits, especially those of New England, may be properly considered.

It will be found that considerable space is devoted to the occurrence of ground waters in formations which, like the granitic rocks, are of comparatively small importance as sources of public supplies. The reason for this is that very little has been published concerning the yield of rocks of these types, at least in a form readily available to water supply officials. Such rocks are, nevertheless, likely to become of increasing importance as supplementary if not primary sources of supplies for small villages and towns.

AVAILABLE GROUND WATERS IN GRANITIC ROCKS.

Granitic rocks, with which are here included traps, the various gneisses or banded granites, and the laminated crystalline schists, constitute the country rock underlying more than half of the entire area of New England, and, on the whole, are the least prolific as regards water supplies of any class of rock we are likely to encounter in this region. The range of yield is, nevertheless, fairly well established, and while individual wells may vary greatly, the quantity of water that would be available to a series of wells, such as those of a small water supply system, may be estimated with a fair degree of approximation.

Controlling Factors. — The water in granitic rocks includes that in the pore spaces between the grains and that in the joints or seams and other fissures. The former have been found by numerous laboratory tests to average about 1 per cent., or about 0.3 of a quart per cubic foot. Within a radius of 500 ft. from a 300-ft. well the supply thus stored would be approximately 17 600 000 gal. Unfortunately, however, all of this is firmly held within the rock by the force of capillarity, and hardly a drop is yielded to wells.

The supplies of the wells ordinarily come from a single source, the joint planes or seams which cut the rock in various directions

from vertical to horizontal. These are familiar to all of you who have ever examined a large quarry. The common vertical or highly inclined joint is that represented by the broad, smooth, iron-stained surface that often forms one of the sides of the quarry or that cuts the quarry face as a vertical seam. Plate X shows several such joints dividing the rock into a series of sheets. The horizontal joints are the flat or curved seams found in the upper portions of most hillside quarries, as show in Plate XI. They are poorly developed and often practically absent in valleys or where the hills or slopes are thickly covered with earth or other deposits.

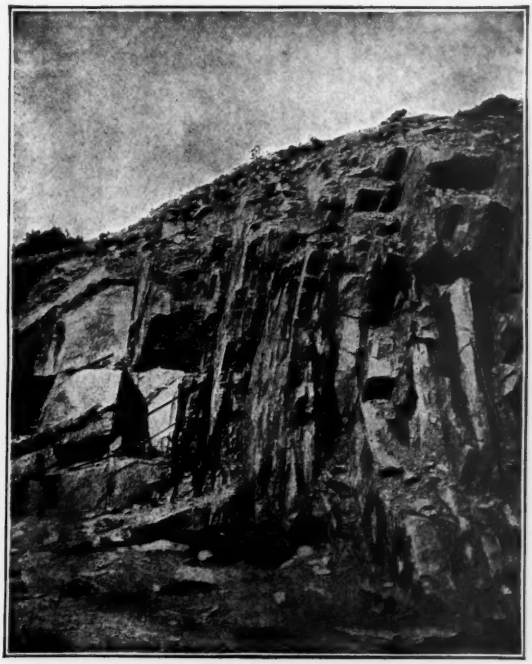
The number and character of the joints within the area tributary to a well are not, however, the factors ultimately determining the supply, for the water so held would be ordinarily exhausted within a few hours if it were not for replenishment, which is regulated by the character of the covering over the rock and the topographic conditions in the vicinity.

Some years ago, Mr. E. E. Ellis, of the United States Geological Survey, spent a season under my direction in the investigation of the granitic rocks of Connecticut. His results* are the basis of many of the following statements.

Considering the granitic rocks of New England, of which the Connecticut rocks are fair representatives, it appears that the average spacing of the vertical or highly inclined joints of a given series is something over 10 ft., but when those of different directions or inclination are included, it probably averages more nearly 5 ft. Horizontal joints often occur as close as a foot apart in the upper 20 ft., but at 50 ft. they range from 6 to 30 ft. from one another.

At the surface, the vertical joints are frequently wide and gaping, but they become much narrower with depth, fully half of their number dying out in the first 150 ft. The average width has been estimated, from careful study of a large number of quarries, at 0.01 in. at depths of 50 to 300 ft. The horizontal joints are rarely more than mere seams.

* Occurrenceof Water in Crystalline Rocks. United States Geological Survey, Water Supply Paper 160, pp. 19–28. Ground Water in the Crystalline Rocks of Connecticut. Water Supply Paper 232, pp. 54–103.



SHEET OR PARALLEL JOINTING IN GRANITE. (PHOTO. BY U. S. GEOL. SURV.)
SUCH SHEETED ZONES ARE OFTEN PERSISTENT FOR LONG DISTANCES
AND GENERALLY YIELD CONSIDERABLE WATER TO WELLS.

HORIZONTAL JOINTING IN GRANITE, SHOWING SEEPAGE OF WATER FROM JOINT PLANES. (PHOTO. BY U. S. GEOL. SURV.) JOINTING OF THIS TYPE IS BEST DEVELOPED AT THE SURFACE, AND YIELDS WATER TO SHALLOW WELLS.

The ordinary vertical joint commonly extends for several hundred feet before dying out or joining another fracture, while the principal or master joints, especially those along which there has been faulting, may extend some miles. The sheeted zones formed by a series of closely spaced parallel joints, Plate X, are also rather persistent. It is to be noted, however, that the portions of joints sufficiently open to be water bearing are usually of limited extent. This is indicated by the fact that salt water rarely penetrates more than 500 ft. from the coast and has never, so far as known to the writer, entered wells located more than 1 000 ft. away. The continuity of the horizontal joints rarely exceeds a few hundred feet.

The attitude or inclination of the joints is an important feature, for unless they are more or less inclined they will not be intersected by a well. In the average New England well in granitic rocks, the number of inclined joints encountered is approximately as follows: 0–100 ft., 4; 100–200 ft., 3; 200–300 ft., 2; 300–400 ft., 1; more than 400 ft., less than 1 per 100 ft.

In addition to the vertical or inclined joints of the regular systems, there must be a certain number of connecting joints joining the various members of a series if a well is to afford any considerable supply. Fig. 1 shows the nature of such an intersecting system.

From the number and character of the joints it is possible to estimate the quantity of water stored in the rocks. I have elsewhere* estimated that with a double system of joints, each with the fractures at an average distance of 5 ft. from one another, there would be about 1 cu. in. of water to 125 cu. ft. of rock. This would be equivalent to approximately 8 000 gal. within a 500-ft. radius of a 300-ft. well.

Since this amount of water would be exhausted by a few minutes' pumping, it is apparent that (1) the number and width of the joints must be larger than estimated, (2) the distance from which water is drawn must be greater than assumed, or (3) the supply must be replenished as rapidly as withdrawn. From the studies of scores of quarries we know that there is little chance for the

* Total Amount of Free Ground Water in the Earth's Crust. United States Geological Survey, Water Supply Paper 160, p. 70.

first, and from the fact that salt water is drawn in from the sea for only short distances, while wells more than a few hundred feet apart rarely affect one another, as they would be sure to do if the joints extended for any considerable distance, it is equally certain that in the majority of cases the water can come from little if any greater distance than postulated. There is every reason to believe, therefore, that the supplies of wells in granitic rocks come, in practically all cases, from the coverings or feeders of overlying material, the quantity being determined by the nature of the feeder and the width of the joints through which the water is transmitted to the well. The intercommunication of soil and rock waters is further indicated by the head of the

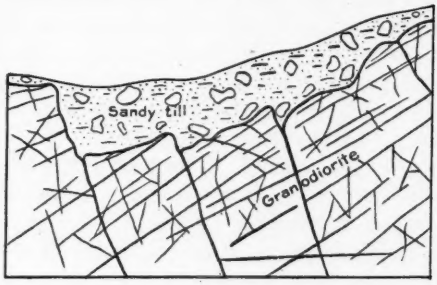


FIG. 1.

DIAGRAM SHOWING INTERCOMMUNICATION OF JOINTS, AND A SURFACE "FEEDER" OF TILL. (H. E. GREGORY.)

waters in the rock wells, which is practically always controlled by the level of the adjacent surface waters, although direct connection may be entirely cut off by the well casings. The chemical differences in the characters of the waters so often noted are the result in part of differences in source and in part of chemical reactions or occasionally of mechanical filtration.

The effect of the soil covering upon the entrance of waters into a rock must be apparent to all. If the rock surface is bare, the rain will be shed, as from the roof of a house, without absorption. If, on the other hand, it is overlain by a porous soil (Fig. 1), the rain will be taken up as it falls and held as in a sponge, to be

subsequently slowly yielded to the rock beneath. The thicker the soil mantle, the greater and more permanent will be the supply. Vegetation, to a certain extent, aids absorption, but it more than doubles the loss by evaporation and transpiration. Frozen soils will naturally be practically non-absorptive.

Topography, or surface relief, also has much to do with the yield of wells in granitic rocks. On slopes, the water is shed quickly, and the feeders above the rock hold less water. In valleys, if the covering is at all thick, the materials over the rock surfaces are always saturated. On the broader hills and on plateaus or upland plains the quantity of water held in the feeders is less than in the valleys but more than on the slopes.

YIELD OF WELLS IN GRANITIC ROCKS. — Having considered the various factors controlling the ground-water supplies in crystalline rocks, it remains for us to apply them to our estimates of yield. The results may be most concisely shown by means of a table.

TABLE 4.

ESTIMATED YIELD OF WELLS IN GRANITIC ROCKS.
(Gallons per Minute.)

Depth of Well. (Feet.)	Diam. of Well. (In.)	No Cover to Rock.			Medium Cover to Rock.			Thick Cover to Rock.		
		Slopes or Sharp Hills.	Plateaus or Upland Plains.	Valleys.	Slopes or Sharp Hills.	Plateaus or Upland Plains.	Valleys.	Slopes or Sharp Hills.	Plateaus or Upland Plains.	Valleys.
100–200	4	3	4	6	8	15	20	15	20	25
"	6	4	5	8	10	20	25	20	25	30
"	8	5	6	10	12	24	30	25	30	35

The figures of the above table are the average estimated permanent yields. Individual yields may be considerably greater or less than indicated, ranging from 0 in the smaller wells on slopes to over 200 gal. a minute in the larger wells in valleys. Initial yields are sometimes, but not always, much higher than the permanent yields, one well with which I am familiar having dropped from 250 to 30 gal. a minute as soon as the reserve

supply was exhausted. Many apparent variations from the normal are explainable by the influence of factors at some distance from the well. Thus a well sunk on a bare rock surface may sometimes yield much more than the quantity indicated in the table, for the reason that adjoining areas, from which a part of the supply comes, may have a cover or feeder of some thickness.

Ordinarily wells more than 500 ft. apart will not interfere appreciably with one another. Wells 200 ft. apart commonly yield not less than two thirds the sum of the normal individual yields. Sometimes wells located only a few feet from one another are entirely independent as to supplies.

The average reported yield for all wells in granitic rocks in Connecticut was about 15 gal. per minute, but many of the wells were less than 100 ft. in depth, and few were pumped to their full capacities. It seems likely that 20 to 25 gal. a minute is more nearly their actual average capacity. Probably not more than 1 in 50 of the wells fails to obtain water. The conditions in similar rocks in other parts of New England are essentially the same.

At a number of localities in New England granites have been utilized as a source of public supplies for small villages, but the limitations of the area tributary to any well or group of wells will prevent the use of such rocks as sources of supply for towns of any size.

AVAILABLE GROUND WATERS IN QUARTZITES.

A quartzite may be defined as a siliceous or quartz sandstone in which the original pore spaces have been filled with a silica cement, forming a dense, hard, compact rock even more non-absorbent than granite.

It is, however, a rock which is generally more or less broken by joints or seams similar in character to those of granitic rocks and likewise characterized by the presence of considerable water.

Nowhere in this country are rocks of this class of any considerable importance as water producers, although many farm wells draw moderate supplies from the quartzites in Minnesota and elsewhere. That they are not more extensively utilized is due, in

a large measure, to the presence of overlying sands, gravels, or glacial drifts which will yield more copious supplies. Their great hardness, also, makes drilling both slow and expensive.

It is probable that, on the whole, jointing is fully as well developed in quartzites as in granitic rocks, and that, under similar conditions, they will yield quite as much water as the latter. Except, however, for villages and very small towns, we should not look to quartzites as sources of public supplies.

AVAILABLE GROUND WATERS IN SLATES AND SHALES.

Slate forms the country rock beneath the greater part of southern Maine, and is found in smaller isolated areas in the other New England states. Of these local slate areas, that underlying Boston may be mentioned. Owing to the scanty population and the abundance of water in the surface deposits over the greater part of the slate areas, only a moderate amount of drilling has been done. My associate, Mr. Frederick G. Clapp, however, has collected data from more than 200 wells in Maine in connection with work for the United States Geological Survey,* while I have myself collected the records of a considerable proportion of the deep Boston wells. The information regarding the waters of horizontal shales was collected by myself and assistants in Minnesota, Ohio, and elsewhere.†

CONTROLLING FACTORS. — Slates and shales normally contain in their pores about 4 per cent., or 1.2 quarts of water per cu. ft., or four times as much as granite. This is equivalent to about 70 000 000 gal. within a radius of 500 ft. from a 300-ft. well, but, as in the granitic rocks and limestones, none of it is available to wells.

There are marked differences in the manner of occurrence of water in slate and in shale, for which reason it is necessary to bear in mind the differences in the two rocks. Shale is a soft, fine-grained rock resulting from the consolidation of clay, and

* Occurrence and Composition of Well Waters in the Slates of Maine. United States Geological Survey, Water Supply Paper 258, pp. 32–39, 1911.

† Geology and Underground Waters of Southern Minnesota. United States Geological Survey, Water Supply Paper 256, 1912. Underground Waters in Southwestern Ohio. United States Geological Survey, Water Supply Paper 259, 1912.

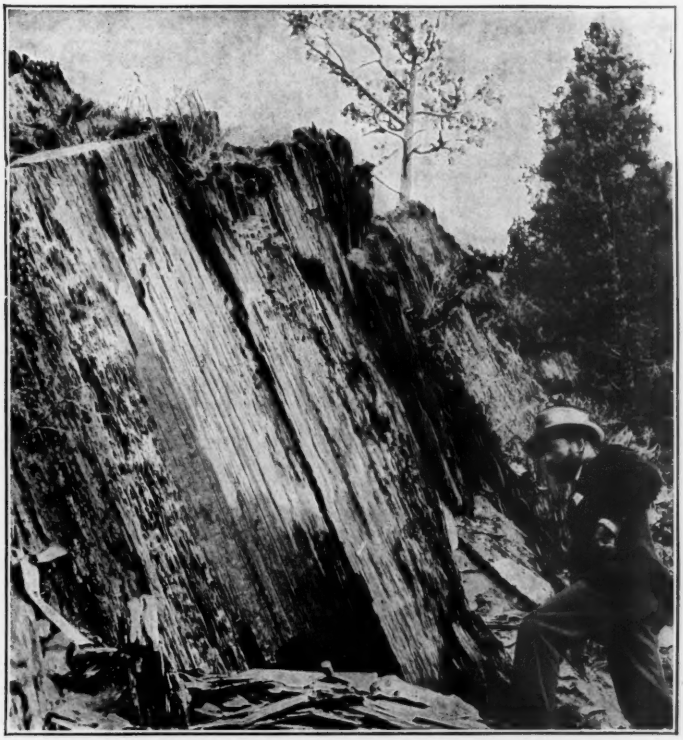
tending to split into thin plates parallel to the bedding or stratification. There is very little true shale in New England, but it is a very important rock west of the Alleghanies. Its beds are generally horizontal or moderately inclined, rarely on edge.

Slate is a harder and denser rock than shale. In most cases, the original bedding planes have been sealed, but it generally has a strong tendency to split along vertical or highly inclined planes as shown in Plate XII. These parting planes are due to pressure instead of to stratification, and are known as cleavage planes.

The waters of shales occur both in joints and in the bedding or lamination planes. The joints are fewer in number than in granitic rocks, but are, perhaps, somewhat more open, although well records do not indicate that they are water-bearing to any greater extent than those of granites. The lamination planes vary from a fraction of an inch to a foot or more apart, but, being horizontal, the weight of the overlying rock tends to keep most of them tightly closed. Comparatively few are water-bearing.

In *slates*, the jointing is much more strongly developed than in shales, the number of the seams often even exceeding those in granitic rocks and carrying correspondingly greater quantities of water. In addition there is often an equal or even greater quantity stored within the cleavage planes, for, being vertical or highly inclined, the latter are less affected, at least at moderate depths, by the weight of the overlying strata than are the bedding planes of the shales. They have a greater tendency, therefore, to remain open and afford passages for the downward percolating waters.

On the whole, it seems probable that the slates contain several if not many times the quantities of water held by equal bulks of granitic rocks. Neverthless, since the lateral extent of the joint and cleavage planes has been shown by the behavior of adjacent wells and wells near the margin of the sea to be even less than of those in granitic rocks (Table 4, page 247), it is certain that no well could be supplied for long from the waters stored within the rock. The water must, therefore, be derived mainly from the cover or feeder of overlying material. The part played by such feeders has already been discussed (page 246).



CLEAVAGE IN SLATE. (PHOTO. BY U. S. GEOL. SURV.) THE PRESENCE OF CLEAVAGE PLANES MATERIALLY AIDS THE TRANSMISSION OF GROUND WATERS AND INCREASES THE YIELD OF WELLS.

YIELD OF WELLS IN SLATES AND SHALES. — The comparative estimated yields of slates and shales under different conditions are shown in the following table.

TABLE 5.

ESTIMATED YIELD OF WELLS IN SLATES AND SHALES IN GALLONS PER MINUTE.

Thin Cover to Rock.

(Less than 10 feet.)

Depth of Well. (Feet.)	Diameter of Well. (Inches.)	Horizontal Shales. (Jointing Poorly Developed.)			Inclined Slates. (Jointing Well Developed.)			Calcareous Shales or Slates. (Containing Soluble Layers.)
		Slopes or Sharp Hills.	Plateaus or Upland Plains	Valleys.	Slopes or Sharp Hills.	Plateaus or Upland Plains.	Valleys.	
100–200	4	1½	3	5	6	9	12	Variable, according to whether or not the well encounters solution passages. Average 25 to 50 per cent. more than non-calcareous slates.
,,	6	2	4	6	8	12	14	
,,	8	2½	5	8	10	14	16	

TABLE 6.

Thick Cover to Rock.

(More than 50 feet.)

Depth of Well. (Feet.)	Diameter of Well. (Inches.)	Horizontal Shales. (Jointing Poorly Developed.)			Inclined Slates. (Jointing Well Developed.)			Calcareous Shales or Slates. (Containing Soluble Layers.)
		Slopes or Sharp Hills.	Plateaus or Upland Plains.	Valleys.	Slopes or Sharp Hills.	Plateaus or Upland Plains.	Valleys.	
100–200	4	4	6	10	20	25	30	Variable, acording to whether or not the well encounters solution passages. Average 25 to 50 per cent. more than non-calcareous slates.
,,	6	5	8	12	25	30	40	
,,	8	6	10	15	30	40	50	

The above estimates of approximate yields are subject to the same limitations and qualifications as those given for the granitic rocks on page 247.

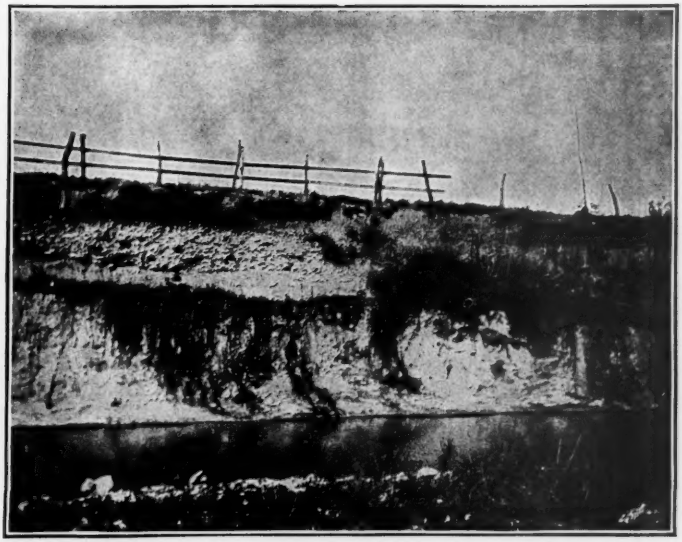
It is to be noted that the yield of horizontal shales where the covering is thin is very small. This is due largely to the infrequency of joints, in the absence of which the waters find great difficulty in entering the rock, for the reason that the shale layers are themselves essentially impervious to the passage of water. Many wells on slopes are failures owing to free lateral drainage (Plate XIII). Even with thick covers or feeders, the supplies of horizontal shales are, for the reasons indicated, less than those of granitic rocks.

In the slates proper, on the other hand, the supplies usually average slightly higher than in the granites and similar rocks, especially in the deeper wells, for the reason that both joints and cleavage planes contribute to the yield.

In the calcareous slates and shales, or those containing considerable quantities of lime, solution passages are often dissolved along the limey layers. These passages are frequently half an inch or more in diameter and extend for long distances. When encountered by wells they often yield good supplies, although the ultimate yield is generally controlled by the rate of absorption from some more or less distant feeder.

Adjacent slate and shale wells are, perhaps, more likely to interfere with one another on pumping than are wells in the granitic rocks, but the effect of the interference is commonly less serious. Usually, wells over 200 ft. apart will give at least three fourths of the sum of their normal individual yields.

The percentage of unsuccessful shale wells on slopes is, when the covering is thin, quite high, probably 1 in 5 failing to get even enough for family use. With thick coverings, the number of failures is probably not more than 1 in 10. With inclined slates and the calcareous varieties of slate and shale the number of failures is probably about the same as in granite, or about 1 in 50. When sunk close to salt water, the percentage of failures is considerable, and indicates that it is undesirable to drill within 500 ft. of the shore.



SEEPAGE FROM STREAM BANK. (PHOTO. BY U. S. GEOL. SURV.) ILLUSTRATING MANNER OF DRAINAGE OF ROCKS AND SOILS ON OR NEAR SLOPES.

AVAILABLE GROUND WATERS IN LIMESTONES.

Limestones, including the crystalline varieties known as marbles, are found principally in northern Maine and in a more or less interrupted belt along the western edge of Vermont, Massachusetts, and Connecticut, although small areas occur elsewhere in New England. In the Mississippi and Ohio valleys and at many other points in the West and South there are formations of great importance.

Controlling Factors. — Limestones have an average porosity of about 5 per cent. and will hold about 1.5 quarts of water per cu. ft., or some 88 000 000 gal. within a radius of 500 ft. of a 300-ft. well, but, as in slates and granites, this is so strongly held by the force of capillarity that practically none of it is available to wells.

The available supplies from limestones come, in nearly every case, from solution passages. These are dissolved by percolating waters wherever there is an opportunity for circulation, generally along some fault (Plate XIV, Fig. 1), joint, or bedding plane, especially at the contact with some shaley or other impervious layer. At first the openings are very small, usually only a fraction of an inch in diameter, but there is a general tendency for the water movement to become concentrated along certain lines, with the result that tubular passages, varying from a few inches to many feet in diameter, are eventually formed. The smaller passages often form a ramifying network along bedding planes, as shown in Plate XIV, Fig. 2.

The largest passages are usually formed at or above drainage level, that is, above the level of the valleys into which the limestone waters drain. Our well-known caves, such as Mammoth, Wyandotte, etc., are examples of this type. At great depths the circulation of water is less rapid and the passages are smaller. Nevertheless, as indicated by water-worn specimens brought up in drilling, passages a foot or more in diameter occur at depths of more than 1 000 ft.

The length of the larger passages is often considerable. One passage in the Mammoth Cave of Kentucky is nearly 5 miles in length, while certain surface features, such as great sinks, indicate that passages of several, if not many, times this length may occur.

The water supplies of limestones, unlike those of most other classes of rocks, are not solely, and possibly not even chiefly, dependent on the presence of overlying soil or other feeders. A large quantity of water, on the contrary, passes downward through sinks or basin-like depressions connecting with the underground passages. Through these, the surface waters enter the rock directly and without filtration. Whole streams, sometimes flowing millions of gallons a day, sometimes disappear into cavernous passages in the limestone.

From the preceding it will be apparent that the free water in limestones will far exceed that of the granitic rocks and the slates and shales, and will often, as a matter of fact, be sufficient to supply a well indefinitely without the aid of the usual feeder.

The ramifying networks of small passages, previously mentioned and illustrated (Plate XIV, Fig. 2), are more dependable sources of supply than are the large passages, since they are generally of considerable lateral extent as compared with the tubular passages. A well may miss the latter entirely, even though there may be several in its immediate vicinity, but it will rarely fail to encounter at least one of the broader bedding planes. The supplies of the latter, however, are usually more limited than those of the big passages.

Topography is a far more important factor in determining the yield of limestone wells than of those of any other class of rock. The reason for this is the open character of the water-bearing passages, which commonly permit the limestone waters to freely drain into the adjacent valleys, thus preventing the accumulation of reserve supplies. Large permanent supplies are seldom found above drainage or valley level, except where large streams of moving water are encountered. Often it will not be the valley nearest to the well that will determine the drainage level, but rather some distant valley into which the underground stream eventually discharges.

It is to be borne in mind that whenever limestone wells are considered as a source of public supplies, there is always considerable danger of contamination, owing to the entrance of much of the water into the ground through sinks and without filtration.

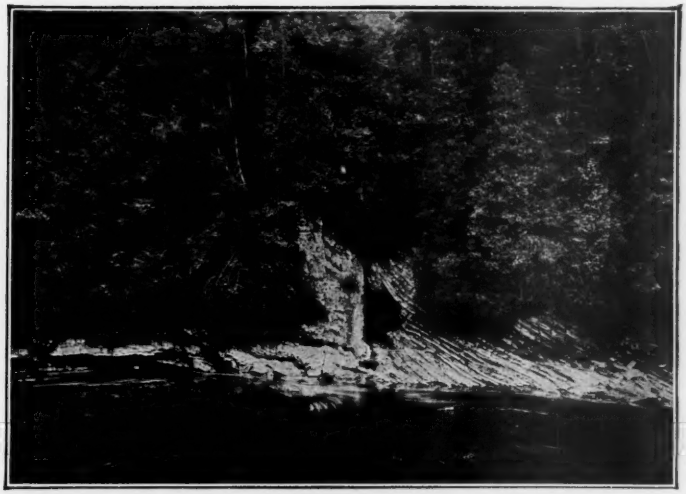


FIG. 1.

WATER PASSAGE ON FAULT-PLANE IN LIMESTONE. (PHOTO. BY U. S. GEOL. SURV.) SUCH PASSAGES OFTEN AFFORD LARGE QUANTITIES OF WATER TO WELLS.

FIG. 2.

NETWORK OF SOLUTION PASSAGES ALONG BEDDING PLANES IN LIMESTONE. (PHOTO BY U. S. GEOL. SURV.) THESE SMALL (½-INCH) PASSAGES EXTEND IN A RAMIFYING NETWORK OVER AREAS AND YIELD MUCH WATER TO WELLS.

Such waters must always be carefully watched for any sudden increase in chlorine or the appearance of bacilli coli.

YIELD OF WELLS IN LIMESTONE. — Too few wells have been sunk in the limestones of New England to warrant any broad conclusions, but I have had the opportunity, in connection with investigations for the United States Geological Survey in Ohio and Minnesota, to study the yield of limestones under a wide range of conditions. From these investigations* it appears clear that the yield of limestones, except where very near the edge of a valley into which their waters may drain, will average not less than 50 per cent. greater than those from slates and shales, as set forth in the tables on page 251. The maximum possible yield of limestone wells is many times that of wells in the latter rocks.

Compared with sandstones, on the other hand, the average yield of wells in limestone is comparatively small, although individual wells encountering large solution passages may run as high or higher than the largest sandstone well. In southeastern Minnesota practically every one of the scores of public supplies derived from rock wells obtains its water from sandstone, although limestone is equally and often even more convenient of access and its water equally good from the chemical and sanitary standpoint.

The average yield of a limestone well under unfavorable conditions, as on slopes with thin coverings, is probably about 25 per cent. less than that of a sandstone well in the same situation. Below drainage level and beneath thick coverings, the average yield of limestone wells is estimated to be 50 per cent. to 75 per cent. less than wells in sandstone.

It is not considered advisable, owing to the excessively wide variations of individual wells, to attempt to show the probable average yield of limestone wells by means of a table. The foregoing comparisons will, however, afford a fair idea of the quantities to be expected from wells of this class. It may be said that, in general, limestones will afford ample water for domestic and farm purposes, and, when beneath drainage level, will ordinarily

* Geology and Underground Waters of Southern Minnesota. United States Geological Survey, Water Supply Paper 256, 1912.

Underground Waters in Southwestern Ohio. United States Geological Survey, Water Supply Paper 259, 1912.

furnish sufficient quantities to supply small villages and occasionally large villages and even towns of considerable size. The yield of limestone wells is not usually materially affected by their diameters, except insofar as the size may limit the capacity of the pumps used.

AVAILABLE GROUND WATERS IN SANDSTONES.

The sandstones of New England are mostly found in the Connecticut Valley lowlands of Massachusetts and Connecticut, where they underlie the river and the broad, flat terraces, several miles in width, which border the stream on both sides. They are known as the "red-rocks" from the prevailing reddish or brownish color. Other local areas of sandstone, largely of a grayish type, are found at a number of points.

The sources of information concerning the waters of the sandstones of New England are the investigations for the United States Geological Survey by H. E. Gregory, W. H. C. Pynchon, and the writer, while the data from other parts of the country are drawn from the Survey reports on southwestern Ohio, southern Minnesota, and the states on the east flanks of the Rocky Mountains.*

CONTROLLING FACTORS. — The greater part of the water in sandstone occurs, as in most other rocks, in the pore spaces between the grains, but unlike the rocks previously considered, these pore spaces are large, mostly supercapillary, and usually give up the greater portion of their supply to wells.

Most sandstones are composed of mixtures of coarse and fine grains, which are bound together by cements of lime, silica, or

* Underground Water Resources of Connecticut. H. E. Gregory, United States Geological Survey, Water Supply Paper 232, pp. 105–138, 1909.

Drilled Wells of the Connecticut Valley. W. H. C. Pynchon, United States Geological Survey, Water Supply Paper 110, pp. 65–74, 1905.

Triassic Rocks of the Connecticut Valley as a Source of Water Supply. M. L. Fuller, United States Geological Survey, Water Supply Paper 110, pp. 95–112, 1905.

Geology and Underground Waters of Southern Minnesota. C. W. Hall, O. E. Meinzer, and M. L. Fuller, United States Geological Survey, Water Supply Paper 258, 1911.

Underground Waters of Southwestern Ohio. M. L. Fuller and F. G. Clapp, United States Geological Survey, Water Supply Paper 259, 1912.

The High Plains and their Utilization. Willard D. Johnson, United States Geological Survey, 21st Annual Report, part 4, pp. 601–674, 1900; 22d Annual Report, part 4, pp. 631–669, 1901.

Also numerous papers by N. H. Darton, G. K. Gilbert, and Erasmus Haworth. (See bibliography of Geological Survey publications on ground waters, Water Supply Paper 120, 1905.)

iron. The extent to which these cements have filled the original pores and thus partially closed the intercommunicating passages between the pore spaces regulates, to a large degree, the freedom of movement of the water within the rock, and largely determines the yield to wells. Inasmuch as the cementing is naturally more complete where the grains and pores are small, it follows that

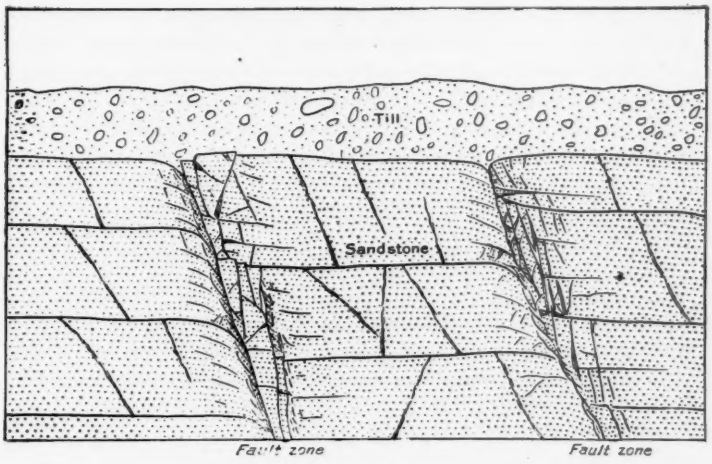


FIG. 2.

DIAGRAM SHOWING CRUSHED ZONES ALONG FAULTS IN THE SANDSTONES OF THE CONNECTICUT VALLEY, WITH OVERLYING FEEDER OF TILL. (H. E. GREGORY.)

the presence of fine material, especially silt, in sandstone is an important factor in determining yield.

In the finer and more silty sandstones which have, let us say, an average porosity of 5 per cent., only about one fifth will be yielded to wells, while four fifths of the water will remain permanently in the rock. In the more coarse and open varieties, whose porosity is sometimes as high as 25 per cent., about three fifths will be yielded to wells and only two fifths remain behind. In the first instance the yield will be equivalent to 0.3 quarts to each cubit foot of sandstone; in the second, to 4.5 quarts.

The yield of a rock holding the latter quantity, if it is of any considerable thickness, is enormous. With a bed only 10 ft. thick there would be stored in a single acre 490 000 gal. Since a well in sandstone may draw from scores if not hundreds or even thousands of acres, the possibilities of obtaining large supplies for public purposes are usually very good.

Although a sandstone bed is usually more or less saturated throughout, the movement of the water, owing to the compactness of grain, may be comparatively slow and the direct yield to a well somewhat limited. Usually, however, there are more or less well-defined bedding planes in the rock, and to these the waters are delivered from the pores over considerable areas. A well encountering such a bedding plane will obtain far more water than it would otherwise secure. There is also a strong tendency toward concentration of movement within the rock along beds or layers of shale.

Joint planes play a far less important part in determining the water-bearing capacity of a sandstone than in the crystalline rocks and slates. Nevertheless, they sometimes afford passages for large quantities of water. This is especially true where there has been faulting along the joint planes and the rock has been more or less crushed and broken, as shown in Fig. 2, which is a section of the sandstone in the Connecticut Valley. The

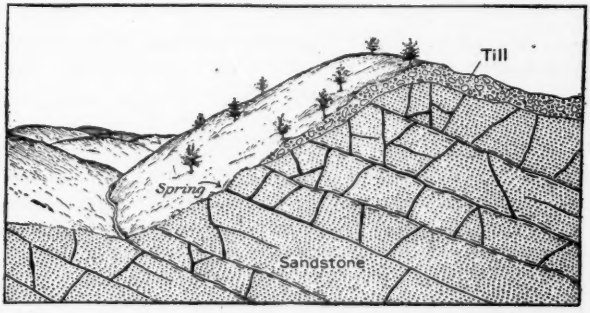


FIG. 3.

DIAGRAM SHOWING DRAINAGE OF SANDSTONE SLOPES BY SPRINGS. (H. E. GREGORY.)

exceptional yield of certain wells at Hartford, Conn., which is from three to five times that of the usual well in similar rocks in the vicinity, is attributed to such a crushed zone.

The action of the soils or other feeders overlying the outcrops is much the same as in other rocks, but since the sandstones are themselves absorbent, the presence of feeders is not so vital.

Topography has a strong influence on the yield of sandstone wells. It is not so much, however, that the rainfall is quickly shed from the slopes as it is that the sloping surfaces cutting the sandstone beds permit the easy escape of their waters (Fig. 3).

YIELD OF WELLS IN SANDSTONE. — The average estimated yield of wells in sandstones of different types and under varying conditions of topography and depth are given in the following table.

TABLE 7.

ESTIMATED YIELD OF WELLS IN SANDSTONES.

(In Gallons per Minute.)

Diam. of Well. (Inches.)	FINE TO MEDIUM GRAINED AND SILTY SANDSTONES.				COARSE OR OPEN SANDSTONE.			
	Depths 100 to 300 Feet.			Deep Wells.	Depths 100 to 300 Feet.			Deep Wells.
	Slopes.	Upland Plains.	Valleys.		Slopes.	Upland Plains.	Valleys.	
4	15	30	40	45	20	100	125	150
6	20*	40*	60*	70	25	150	200	350
8	25	50	70	85	30	200	250	500
10	30	60	80	100	35	250	300	600

As in other rocks, individual wells in sandstone vary greatly from the average yields according to local conditions. Practically no well in sandstone, however, unless near the immediate edge of a sharp drop, will fail to get some water, and under favorable conditions the supply may reach 1 000 gal. a minute or more, or upwards of a million and a quarter gallons per day.

* Actual averages computed for ninety wells in Connecticut are 17, 43, and 64 gal. per minute respectively for slope, upland plain, and valley wells. (H. E. Gregory, United States Geological Survey, Water Supply Paper 232, p. 137, 1909.)

The diameter of the well is of more importance in drilling in sandstone than in most other rocks for the reason that water enters from every point on the sides and any increase of exposed area tends to increase the rapidity of entrance of the supply. The effect is greatest in the silty sandstones. In the very open varieties the diameter is less important, as the water is often able to enter as fast as required by the pumps regardless of diameter. Large diameters are of advantage through the increased size of pumps that may be used.

The small yield of wells of moderate depths (100 to 300 ft.) situated on slopes is due to the fact that, while the bottom of the well may be below drainage, the head of the water, which determines its rate of entrance, is relatively low, owing to the drainage of the supplies from the upper rocks. Under hills and upland plains this leakage is not so important, and the yield of wells is noticeably higher. Under broad plains the quantity afforded by a well approaches that given by one in the valley. Deep wells, under which head may be included those from 300 to 1 000 ft. or more in depth having not less than four fifths of their depth below drainage level, give still larger supplies.

The yields of the table are for sandstones of the ordinary types. The dense hard varieties, such as occur in the vicinity of Boston, in Narragansett Bay region, etc., often approach quartzites in character. In such rocks the water supplies are determined by the jointing, and vary but little in quantity from those secured from quartzites and granites.

Owing to the open character of the rock, adjacent wells in sandstone almost always interfere with one another if the withdrawal is in excess of the inflow from other parts of the rock. The yield of nearby wells may be less than 50 per cent. of the sum of their yields when pumped separately, but one well seldom robs the entire supply of its neighbors, as is sometimes the case in granite, shale, and quartzite wells. When the water-bearing sandstone is of considerable thickness and the replenishment rapid, the wells may often be pumped to their full capacity without serious interference.

The sandstones of the Connecticut Valley are medium grained and somewhat silty. Their average quantitative possibilities as

sources of public supply are fairly well shown by the table, although locally the supplies will run much higher. Their mineralization must, however, be carefully considered in connection with any project for their development.

In the West, the Dakota and other sandstones furnish water for scores if not hundreds of villages and towns, the consumption of some of which reaches several million gallons per day. Over broad areas these sandstones are unfailing sources of supply where the demand does not exceed one or two million gallons a day.

AVAILABLE GROUND WATERS IN CONGLOMERATES.

Conglomerates are consolidated gravels. They consist of pebbles of various sizes, the spaces between which were originally filled with sand or silt which has since hardened into a more or less firm bond. Since in all deposits of mixed materials the finer particles control the water movements, the conglomerates are usually to be classed with sandstones as regards their water-bearing capacities. The table of yields of wells in the latter is, in a general way, applicable to the conglomerates, although it is probable that, on the whole, the average yields of the conglomerate wells are slightly (15 to 20 per cent.) less than those in sandstones, for the reason that the porosities of the former are usually somewhat less than those of the latter, while they are also likely to be somewhat more silty.

In some localities the conglomerates have been so firmly cemented and the pores so completely filled with mineral matter that they have become hard, dense, and non-absorptive. The Boston conglomerates are typical examples of this class. In such cases the available water will be found largely, if not entirely, in the joint or similar seams, and the supplies will be essentially the same as indicated in the table for wells in granitic rocks.

AVAILABLE GROUND WATERS IN CLAYS.

Clays are of extended occurrence in New England, underlying the sandy surface alluvium of many of our river valleys and other depressions, as well as forming the foundation upon which rest certain of our broad sandy plains such as those of Cape Cod.

Clays also underlie the surface deposits throughout a large part of southern Maine and considerable areas of the Champlain valley of Vermont.

CONTROLLING FACTORS. — As indicated in the table on page 238, clays are among the most porous of any of our natural deposits, ranging from 40 to 70 per cent., with a probable average of about 50 per cent. Those who have noted the network of great shrinkage cracks checking the surface of a dried mud flat, will appreciate how much of the original volume must have been water.

The water held in the pores of clays amounts to 3.75 gal. per cu. ft., or 880 000 000 gal. within a radius of 500 ft. of a 300-ft. well. The storage within the limits indicated would, if available, supply 1 000 000 gal. daily for a period of more than two years. Practically none of this, however, is directly available to wells, at least to those in the purer varieties free from sand. This is due in part to the tenacity with which the water is held by capillarity, and in part to the fact that it is practically impossible to keep clay from entering a well with the water in sufficient quantities to prevent its utilization. Anything that will shut out the clay, so that the water will enter free from turbidity, will prevent the entrance of the supply with sufficient rapidity to be of practical value.

Clay, although not in itself an important producer of water supplies, is often of great value as a feeder. Its effect on the yield of the Boston wells has already been pointed out. That it yields clear water to underlying formations while affording turbid water to wells is due to the fact that in the former case the water seeps from broad areas with exceeding slowness, while in the latter, under ordinary conditions of pumping, the velocity of entrance of the water is such that the clay particles are carried along with it.

YIELD OF WELLS IN CLAYS. — Wells in pure clays yield practically nothing under prevailing conditions of pumping. In many clays, however, there are interbedded streaks or strata of sand which sometimes yield considerable quantities of water, although seldom enough for public supplies. It is not practicable to tabulate the yield of clay wells, but it may be said that, in general,

where any water at all is obtained the volume will not vary greatly from those indicated for horizontal shales (page 251).

AVAILABLE GROUND WATERS IN GLACIAL TILL.

Till is the geological term for the heterogeneous unstratified materials left by the glaciers formerly covering the northern half of this continent. In this vicinity it is a mixture of clay and bowlders with some sand, and is often known as bowlder-clay, It is the material of which Beacon Hill and most of the other hills around Boston and in the harbor are composed, as well as hundreds of similar hills in other parts of New England. Other and often more sandy varieties form the general sheet of glacial drift mantling the uplands throughout most of the New England states.

Controlling Factors. — The clayey varieties of till are similar in porosity and water-holding capacity to the clays, and likewise hold tenaciously to their supplies. In the more sandy and gravelly types, on the other hand, the conditions of storage, movement, and delivery to wells are more like those in true sands and gravels. All tills, however, are likely to be characterized by great variations in composition and texture within short distances, as are also the intercalated layers of sand or gravel. The area drawn upon is, therefore, likely to be more restricted than in the relatively uniform and continuous stratified deposits.

In New England, much of the till occurs in hills or as a comparatively thin mantle over rock uplands and in situations topographically unsuited to the development of large supplies. Locally, however, there are thick deposits in the valleys, many of which are sandy and porous. In Ohio, Indiana, Michigan, and other parts of the central United States, the till forms a somewhat uniform sheet, often several hundred or even a thousand feet or more in thickness. This great accumulation practically always contains sandy or gravelly beds of considerable thickness.

Yield of Wells in Tills. — The yield of till wells varies according to the predominance of clay or sand, and to the presence of sand or gravel layers. The more clayey varieties usually yield very little water, while the sandy types sometimes afford supplies approaching those of true sands and gravels. The estimated average yield is indicated in the following table.

TABLE 8.

ESTIMATED YIELD OF WELLS IN TILL.
(In Gallons per Minute.)

Depth of Well. (Feet.)	Diam. of Well. (Inches.)	Clayey Tills.			Sandy Tills.		
		Slopes.	Upland Plains.	Valleys.	Slopes.	Upland Plains.	Valleys.
100–200	4	4	6	10	15	30	50
"	6	5	8	12	20	40	80
"	8	6	10	15	25	50	100

The usual qualifications, already indicated for wells in other materials, apply to till wells. The yields for "sandy types" are for moderately sandy varieties. More porous varieties will approach sandstones or even pure sands in yield.

The diameter of the well in the finer tills is a factor of much importance. Where it is found to be impossible to obtain the needed supply from the ordinary driven or drilled well, a large open well, often from 25 to 75 ft. in diameter, is sometimes successfully used for the development of public supplies.

In general, where the till is of considerable thickness, and not too clayey, it will yield enough water for a small village, but unless sandy or containing sand or gravel layers of some thickness, the yield is seldom sufficient for the larger towns or cities.

AVAILABLE GROUND WATERS IN SANDS AND GRAVELS.

Sands and gravels are of such general distribution in New England that the enumeration of their areas is unnecessary. The greatest single sandy area is in southeastern Massachusetts, comprising Cape Cod and a large part of Plymouth County. The scattered areas are chiefly in river valleys or in broad basins between rock or till uplands. Outside of New England, the chief sandy formations are along the Atlantic coastal plain, the waters of which I described some years ago in a paper in the proceedings of the American Water Works Association.* Extensive sandy

* Proc. Am. W. W. Association, 1908, p. 292.

deposits also underlie the lower Mississippi Valley, while sandy drift, similar to that of New England, occurs throughout the glaciated area of the northern United States and Canada.

CONTROLLING FACTORS. — The water-bearing capacities of sands and gravels are largely a factor of their porosities. Where the grains are all of the same size, the porosity is independent of their diameter. For instance, the large number of small pores in a sand are equivalent in volume to the comparatively small number of large pore spaces in a gravel. When, however, small grains fill the spaces between larger ones, as sand grains between the pebbles of a gravel, the porosities are much reduced.

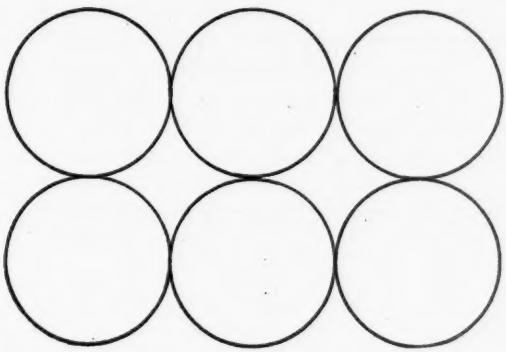


FIG. 4.

ARRANGEMENT OF SPHERICAL PEBBLES TO GIVE MAXIMUM POROSITY OF 47.6 PER CENT.

Although the size of grains in uniform sands or gravels does not affect the porosities, their arrangement is of great importance. When arranged in the loosest possible manner (Fig. 4), they have a porosity of 47.6 per cent.; where arranged in the most compact manner (Fig. 5), the porosity is only 26 per cent. The actual porosities in nature are usually about midway between the two.

In laboratory tests, the porosities of uniform sands and gravels are found to be about 35 per cent., and of mixed pebbles and sand, which is the ordinary condition of our gravels, about 30 per cent.

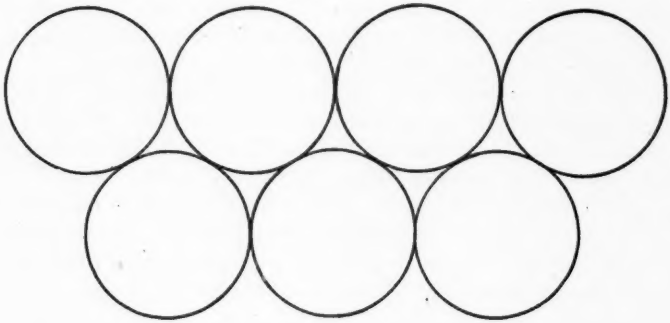


FIG. 5.

ARRANGEMENT OF SPHERICAL PEBBLES TO GIVE MINIMUM POROSITY OF 25.9 PER CENT.

(Fig. 6). In nature the materials are subject to pressure, due to the weight of the overlying deposits, equal to about 1 lb. per sq. in. for every foot in depth. This pressure produces a compacting, according to laboratory experiments with pressures of from 0 to 100 lb. per sq. in. made under my direction by

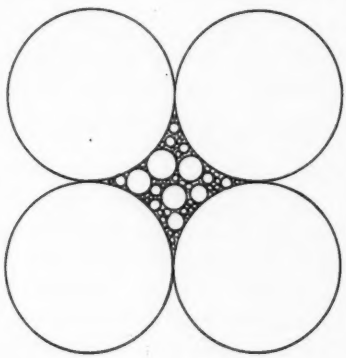


FIG. 6.

ARRANGEMENT OF SPHERICAL PEBBLES AND GRAINS OF DIFFERENT SIZES, GIVING VARIABLE POROSITIES, USUALLY FROM 20 TO 30 PER CENT.

Mr. L. C. Cheminant in connection with some recent investigations for the city of San Francisco, of from 5 to 8 per cent., reducing the actual probable porosity in the ground by an equivalent amount.

When water is withdrawn from a sand or gravel, a certain quantity remains behind as residual moisture, and is not yielded to wells. The quantity thus withheld varies with the size of the grain from 5 per cent. in the gravels to perhaps 20 per cent. in the finer sands or those approaching silts in texture. It still further reduces the effective porosities or available storage. The reductions due to compression and residual moisture are shown in the following table. The last column shows the quantities of water actually available.

TABLE 9.

EFFECT OF POROSITY DEDUCTIONS.

(Per Cent. of Volume.)

Material.	Porosities of Loose Materials. (Laboratory Tests.) Per Cent.	Loss of Porosity Due to Weight of Overlying Material. Per Cent.	Loss Due to Water Remaining in Pores. (Residual Moisture.) Per Cent.	Effective or Available Porosity. Per Cent.
Gravel (mixed sand and pebbles)..	20–30	5–8	4–8	10–20
Sand (medium to coarse).....	30–40	4–6	6–10	15–25
Sand (fine and very fine).....	30–40	0–5	10–25	5–20

The quantity of water stored in the sands and gravels is not the only thing that must be considered. The real determining factor in a permanent supply is the rate of replenishment. In an inclosed basin or other area not receiving outside supplies, replenishment is mainly from the rainfall. The whole rainfall is, of course, not available, large deductions being necessary for evaporation and surface run-off.

UNDERFLOW MEASUREMENTS. — In sand and gravel deposits receiving contributions from outside their own areas, as is the case of most of the formations in stream valleys, a determination

of the rate of underflow is necessary to fix the quantity of accessions from sources other than rainfall. When replenishment occurs from a stream flowing over the surface of the deposits being drawn upon, a still further determination, that of downward percolation, is necessary.

A fairly exact determination of the rate and volume of underflow can be made by actual measurement by the electrical method devised by Prof. Charles S. Slichter, of the University of Wisconsin

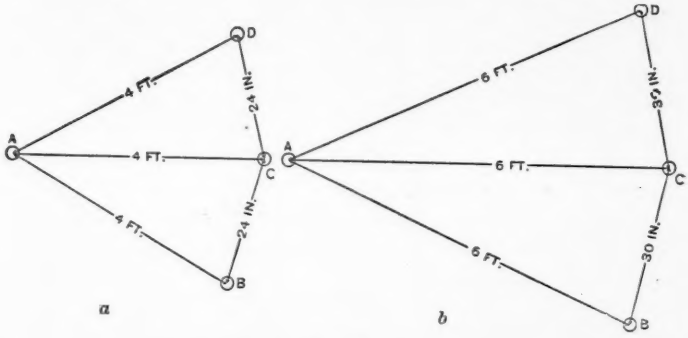


FIG. 7.

ARRANGEMENT OF WELLS IN UNDERFLOW TESTS. (C. S. SLICHTER.)

and the United States Geological Survey. In brief, the method consists in sinking four 2-in. wells in the form of a fan or triangle, as indicated in Fig. 7, the apex of the system being toward the supposed direction from which the water is moving. Common salt or ammonium chloride is inserted in the apex well and the time required for penetration into the other wells taken by electrical recording apparatus or determined from water samples taken and tested at short intervals. A view, showing the apparatus in use, is given as Plate XV, Fig. 2. Detailed accounts of the method and its applications are given in Water Supply Paper 110 of the United States Geological Survey, pages 17 to 31, and in other Survey publications.

The rate of percolation from streams is best determined by the Slichter method used in conjunction with a pumping test.

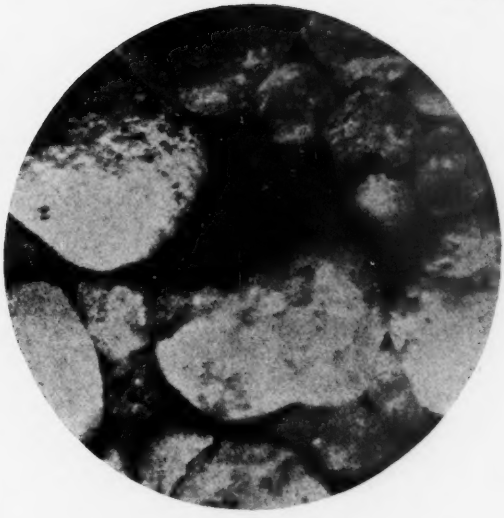


FIG. 1.

COMMON ARRANGEMENT OF GRAINS IN SANDS, SHOWING LOOSE PACKING ORDINARILY PREVAILING. ENLARGEMENT 40 DIAMETERS. (ILLUS. FROM ROCK PRODUCTS.)

FIG. 2.

VIEW OF WELLS, WIRING, AND RECORDER IN UNDERFLOW TESTS. (PHOTO. BY U. S. GEOL. SURV.)

Where a direct test is not made, it is possible to form an approximate idea of the rate and volume of underflow by computations based on temperature, size of grain, porosity, head, etc. Space is not available to go into this question in the present paper, and the reader is referred to the report by Professor Slichter published by the United States Geological Survey as Water Supply Paper 67 (pages 24–30), in which formulas and tables for use in estimating underflows are to be found. Other valuable discussions of the movements of water in sands are to be found in the reports of Allen Hazen and Prof. F. H. King.* It may be stated that size of grain and temperature are factors of the greatest importance. The flow through a sand whose effective size of grain is 1 mm. or about $\frac{1}{25}$ in., which may be regarded as a fairly coarse sand, is 10 000 times that through a clay whose particles have an effective size of .01 mm. The flow at 70 degrees is about double that at 32 degrees. Again, the movement of water through sands of the same size of grains varies with the nature of the packing, a sand with a 40 per cent. pore space having a movement of 2.6 times that through one of similar grain but with packing giving a 30 per cent. porosity.

Something of the actual rates of underflow movements under ordinary conditions is indicated by the following table.

TABLE 10.

COMMON RATES OF UNDERFLOW.

(After C. S. Slichter.)

(Gradient or Head, 10 ft. per Mile; Porosity, 32 Per Cent.; Temperature, 50° F.)

Material.	Diameter of Grain in Millimeters.	Movement in Miles per Year.	Movement in Feet per Year.	Movement in Feet per Day.
Fine sand	0.2	0.01	52.8	0.145
Medium sand	0.4	0.04	216.0	0.6
Coarse sand	0.8	0.16	845.0	2.3
Fine gravel	2.0	1.02	5 386.0	14.76

* Some Physical Properties of Sands and Gravels. Allen Hazen, Report of Massachusetts State Board of Health, 1892, p. 541. Principles and Conditions of the Movements of Ground Water. F. H. King, 59th Annual Report, United States Geological Survey, part 2, p. 59, 1899.

YIELD OF ISOLATED AREAS OF SANDS AND GRAVELS. — The yield of wells in isolated areas is dependent upon the inter-relation of rainfall, evaporation, and run-off. Estimates of the quantities afforded under conditions prevailing in New England are given in the following table, in which part of the figures are the estimates of the New York Commission on Additional Water Supply, based on extended and detailed studies on Long Island in 1903.

TABLE 11.

YIELD OF ISOLATED AREAS OF SANDS AND GRAVELS.

Rainfall. (Inches.)	Estimated Evaporation. (Inches.)	Estimated Run-off as Flood Flow. (Inches.)	Estimated Ground-water Increment. (Inches.)	Yield per Acre per Day. (Gallons.)	Acre Yield per Minute per Ten-hour Day. (Gallons.)
35*	17*	3*	15 *	1 116	1.85
37½	17	4	16½	2 228	2.03
40	17	5	18	1 339	2.23
42½*	17*	6*	19½*	1 451	2.41
45	17	7	21	1 562	2.60

The foregoing table shows the limitations of yield where there are no ground water additions from outside sources. Under such conditions the yield is essentially dependent upon area.

YIELD OF NON-ISOLATED AREAS OF SAND AND GRAVEL. — When additions from outside the area normally tributary to the wells occur, the supply is largely dependent upon the rate of underflow. The rate of movement in materials of different sizes has been indicated in the table on page 269. The following table shows the volumes that may be anticipated under varying conditions of porosity and movement.

The figures in the table show the underflows passing given points before pumping has begun. They are the quantities which will normally be available to wells without material readjustment of replenishment conditions.

After the pumps are started, the movement of the water will be greatly accelerated because of the increased gradient resulting from the local lowering of the water table near the well (see

* Report of New York Commission on Additional Water Supply. W. E. Spear, p. 829, 1903.

TABLE 12.

TRANSMISSION THROUGH SANDS AND GRAVELS.
(Per One Thousand Square Feet of Cross-section.)
Head, 10 ft. per Mile; Temperature, 50° F.

Materials.	Porosity. Per Cent.	Relative Flow.	Flow in Gallons per Minute.
Medium sand (Effective size, .4 mm.)	26	1.00	0.4
	28	1.28	0.5
	30	1.61	0.6
	32	1.99	0.8
	34	2.43	1.0
	36	2.93	1.2
Coarse sand (Effective size, .8 mm.)	26	1.00	1.6
	28	1.28	2.1
	30	1.61	2.6
	32	1.99	3.3
	34	2.43	4.0
	36	2.93	4.8
Fine gravel (Effective size, 2. mm.)	26	1.00	10.2
	28	1.28	13.1
	30	1.61	16.4
	32	1.99	20.5
	34	2.43	24.8
	36	2.93	30.0

Slichter, *loc. cit.*, for tables, etc.). Moreover, since a heavily pumped well intercepts and utilizes the underflow over a much greater cross section than 1 000 sq. ft., the supplies actually available at a given point will ordinarily be several if not many times the quantities indicated in the table. The amount and permanency of the supply that may be withdrawn in excess of the normal underflow will be regulated by the readiness with which replenishment by downward percolation from surface sources occurs. This, as previously indicated, is best determined by combined pumping and underflow tests.

UTILIZATION OF ACCUMULATED STORAGE. — The storage capacities of sands and gravels are very great, and in many instances, even though the wells may be drawing from them faster than the water is replenished, the supplies may be sufficient to make it possible to postpone for many years the installation of more

expensive systems, with their attendant increased cost of maintenance and higher interest charges. The following table shows the available supplies in materials of varying porosities after the necessary deductions for compacting and residual moisture have been made. The compacting and residual moisture factors are based on experiments made for the writer by L. B. Cheminant in the laboratories of the Department of Public Works of San Francisco in connection with ground-water investigations for that city.

TABLE 13.

STORAGE IN SANDS AND GRAVELS.

(Gallons per One Thousand Cubic Feet. Porosities are in per cent. of volume.)

Material.	Porosity by Laboratory Test. Per Cent.	Probable Porosity of Undisturbed Material. Per Cent.	Deductions for Residual Moisture. Per Cent.	Available Porosity or Storage Capacity. Per Cent.	Storage in Gallons per 1 000 Cubic Feet.
Very fine sand (approaching silt)	30	30	25	5	374
	30	30	20	10	748
	35	30	25	5	374
	35	30	20	10	748
	40	35	25	10	748
	40	35	20	15	1 122
Fine sand	30	30	15	15	1 122
	35	30	15	15	1 122
	40	35	10	20	1 496
Medium sand	30	30	10	20	1 496
	35	30	10	20	1 496
	40	35	10	25	1 870
Coarse sand	30	30	7	23	1 720
	35	30	7	23	1 720
	40	32	7	25	1 870
Gravel (mixed with sand)	20	16	6	10	748
	25	21	5	16	1 197
	30	25	5	20	1 496
	35	27	4	22	1 646

Applying the figures of the above table to a larger area, we find that a tract of sandy deposits one square mile in extent with

an average depth of saturation of 50 ft. and an available yield of 15 per cent. should afford about 1 568 000 000 gal., or enough to supply a million gallons a day for 1 568 days, or nearly $4\frac{1}{2}$ years.

Since, even in deserts, there are practically always more or less additions to the ground-water reservoirs through replenishment from rainfall or percolation from temporary or permanent streams, the length of time the accumulated storage within the ground may be drawn upon by a water-works system will depend on the difference between such replenishment and the quantity withdrawn rather than on the absolute storage. Since this difference is often slight, at least as compared with the total volume of ground-water reserves, the probable life of a system under such conditions is often sufficient to warrant the installation of relatively expensive and permanent plants.

Sands and Gravels as Sources of Supplementary Supplies. — The utilization of sands and gravels as supplementary sources to eke out deficiencies of existing water supplies is often both practicable and desirable. This may be illustrated by the following hypothetical example, which, however, is probably fairly representative of conditions existing at many points.*

" Let it be assumed that a town of 20 000 people using 1 000 000 gal. daily has a reservoir holding sixty days' supply, or 60 000 000 gal., and that the inflow exceeds the consumption from December

TABLE 14.

Conditions without Wells.

Thirty Days Ending	Regular Supply.	Deficiency.	Amount Remaining in Reservoir.
May 31	30	0	60
June 30	24	6	54
July 30	18	12	42
August 29	12	18	24
September 28	12	18	6
October 28	18	12	None.
November 27	24	6	None.
December 27	30	0	Begins to fill.

* Wells as Sources of Supplementary Water Supplies. M. L. Fuller, *Engineering News*, Vol. 68, p. 474.

1 to June 1, while the deficiency between June 1 and December 1 varies from 0 to a maximum of 700 000 gal. per day in August and September. Let us consider first what would happen if there were no supplementary supply available. This is indicated in Table XIV, in which figures are in million gallons.

"It is seen that, in the absence of any supplementary supply, the reservoir would be emptied by the middle of October, and that for nearly two months the town would be without a reserve supply and dependent solely upon the daily inflow, which would be far below the demands.

TABLE 15.

CONDITIONS WITH WELLS.

Thirty Days Ending	Regular Supply.	Well Supply.	Deficiency.	Amount Remaining in Reservoir.
May 31	30	6	0	60
June 30	24	6	0	60
July 30	18	6	6	54
August 29	12	6	12	42
September 28	12	6	12	30
October 28	18	6	6	24
November 27	24	6	0	24

"The condition with a supplementary supply from wells of only 200 000 gal. daily, or a fifth of the total consumption, is shown by Table XV. This table brings out the fact that, notwithstanding the apparent insignificance of the ground-water supply and the large shortage in the regular supply, the town would go through the season of drought with undiminished consumption and with a minimum reserve equivalent to a twenty-four days' supply as against two months of absolute exhaustion of reserve when the supplementary well supply was not available."

PROPER DEPTH OF WELLS.

There is an almost universal belief that the quantity of ground water increases with depth, and if a well only "goes deep enough" an adequate supply is certain. This, however, is far from the truth. Practically all ground water has its origin in rainfall, and although there is a general tendency of the water to percolate downward, drilling and deep mining have repeatedly shown that beyond certain moderate depths. the supplies rapidly decrease,

many of the deeper wells and mines being practically destitute of water in their lower portions.* The chief causes of this absence of water are the tightening of the seams under pressure in jointed rocks, the filling of the pores by mineral deposition in the sandstones, the absence of outlets — without which the deep circulation of water is much impeded — in limestones, and the interposition of impervious beds of clay or shale in bedded rocks of any description.

Unfortunately many drillers, although by no means all of them, have immediate profits rather than the future development of the drilling business in view, and are inclined to urge their clients to continue drilling long after there are any reasonable prospects of success. They cannot see that a deep unsuccessful well such as the 3 700-ft. well of Belding Bros. Silk Company at Northampton, Mass., or the 4 000-ft. well of the Winchester Repeating Arms Company at New Haven, Conn., will do more to discourage drilling than several successful wells like the 350-gal. well of the New England Brewing Company at Hartford will do to encourage it.

I presume that many drillers, in their optimism, will take exception to the opinions here expressed. I venture, nevertheless, to present the following brief table of "depth limits" based on the investigations of myself and assistants for the Geological Survey in various parts of the country.

TABLE 16.

"DEPTH LIMITS" OF ROCK WELLS.

Quartzite	200– 250 feet
Granite	250– 300 „
Shale	300– 400 „
Limestone	400– 500† „
Sandstone (silty)	400– 500† „
Sandstone (open)	1 000–1 500† „
Sands and gravels	1 500–2 000† „

There will, naturally, be numerous exceptions to the limits indicated, but the additional yields below the depths shown will usually be exceedingly small. If the required volume has not

* Total Amount of Free Water in the Earth's Crust. M. L. Fuller, United States Geological Survey, Water Supply Paper 160, pp. 59–72, 1906.

† Limits largely imposed by the mineralization of the deeper waters.

been secured at these depths, the chances of obtaining a supply from an entirely new well located 100 to 200 ft. or more from the first will ordinarily be at least five times as great as they will be in continuing the original well beyond the limits given.

It should be noted that in the deeper wells the limitations are qualitative rather than quantitative, the waters from below 500 ft. in many of the limestones and below 1 000 to 1 500 ft. in the sands and sandstones often being too mineralized for industrial or boiler purposes and therefore unsuited for public supplies.

CONCLUSION.

In the foregoing pages, I have attempted to indicate the probable average yield of wells in the common types of rocks and unconsolidated deposits encountered in New England. That the supplies in individual cases will depart more or less widely from the estimates is not unlikely. Such variations are bound to follow any attempt to apply average estimates to localities at which the controlling conditions have not been established.

Ground-water problems are seldom simple, and are not to be settled offhand. If given the proper attention, however, they are as susceptible of solution, as has already been stated, as are those of surface supplies. The sooner it is realized that guesswork and rule of thumb are not to be depended upon, but that real investigations are needed, the sooner will the seeking of ground waters be lifted to the plane of other branches of engineering and the sooner will the needless waste in ground-water developments be stopped.

If dependable estimates are required, as they should be in the development of public supplies or other projects involving the expenditure of considerable sums of money, the assistance of a competent engineer who shall have a grasp of the geological as well as the engineering problems will, it goes without saying, be desirable.

Notwithstanding the occurrence and movements of ground waters are dependent almost entirely upon geological conditions, it is by no means the purpose of the writer to advocate the necessity of geological investigations alone, but rather to urge that

geology be recognized, along with hydraulic and mechanical factors, as one of the essential elements to a proper understanding of water-supply problems.

DISCUSSION.

MR. ALLEN HAZEN.* Mr. Fuller has given us a most interesting paper and one that contains information of permanent character, and the Association is fortunate to have it available for reference in its pages. The paper treats of ground water from various rock formations most fully. In New England, the deposits of sands and gravels are the most important sources of ground-water supply, and this part of the subject will need to be more fully covered on some future occasion.

One aspect of the ground-water supply question has impressed itself forcibly upon the speaker's attention in the last years. That is represented by what the speaker has sometimes called "the coal mine basis" of ground-water supply, which is a very different basis from the one that has been ordinarily studied, and which the author has mainly discussed in his paper. This grows out of the fact that there are in many places great deposits of sand and gravel, the pores of which are filled with water which can be drawn out and used, but which are so situated that when the water is removed it will take long periods, perhaps many years, to refill the pores with water. Where such deposits occur, it is sometimes possible to draw water from them for a time in much greater quantities than could be permanently supplied. Such a supply may be compared to a large lake with a small catchment area. Water can be drawn from such a lake at any desired rate as long as the supply lasts.

I have in mind the case where a group of water companies in the course of a term of years supplied an increasing amount of ground water by driving more and deeper wells, and by so doing have lowered the ground-water level over some square miles of area to an extent ranging up to 50 ft. or more. This is not a permanent source of supply. They have been taking water out of an underground reservoir at a greater rate than the natural flow. The time will come when not only will it be impossible to secure

* Civil Engineer, New York City.

additional water from this source, but it will be impossible to maintain the rate of output that has been reached while the ground-water level was being lowered. Other more distant and expensive sources of supply are clearly required to guarantee future conditions. Nevertheless the use of this ground-water supply has been profitable to the companies, and has brought them to a point where their financial resources will justify a larger and more permanent development.

The whole operation is precisely similar to taking coal from a coal mine. The material is there, it can be taken out, it has a value and can be used at a profit, but when it is gone some other sources of supply must be found.

A similar condition also occurs in gravels near and connecting with the ocean. Here it is sometimes possible to draw out the water in the voids at a much greater rate than it will be replaced, and in this case without lowering the ground-water level because the deficiency is made up by sea water which comes into the space in the ground to take the place of the fresh water that is drawn out. Ultimately, of course, sea water will penetrate to the wells and the water will become brackish, and the supply will have to be abandoned.

MR. FULLER. I fully agree with Mr. Hazen as to the importance of sands and gravels as sources of public water supplies in New England. Only a few weeks ago I had occasion to recommend a source which, although the rate of replenishment might be less than that of depletion, had a reserve storage sufficient to furnish the required quantities for many years.

MR. WILLIAM S. JOHNSON.* I want to take issue with the author, Mr. President, on one point, and that is with regard to the value of a pumping test in the investigation of ground-water sources. I have personally investigated some hundred pumping tests, and where the tests were thoroughly made and the results properly interpreted, they have never failed to give a correct interpretation both as to the quality and the quantity of the water. Furthermore, in many of these cases it would have been practically impossible to gain the information by any other means.

In several cases in my own practice I have had courage enough

* Sanitary and Hydraulic Engineer, Boston, Mass.

to go ahead and install works without a preliminary pumping test, and in two or three cases at least I have had cause to regret not having gone to the extra expense of such a test, as it would have shown things which I discovered to my sorrow after the works were built.

Here in New England — and all of what I say applies to New England conditions only — there are no extensive deposits of sand or gravel unmixed with other material. It is only necessary to look at some railroad cut to see what the sand is here in New England, near the surface at least. There are streaks of fine sand, clay and other impervious material, the location and extent of which cannot be determined, even by the most expert geologist, and which may upset all calculations in getting a water supply. A pumping test takes all of these things into consideration and shows just what results are to be obtained under the conditions which actually exist without the necessity of theorizing on the basis of assumptions which may not be correct.

A proper test is not "putting down a test well and making a pumping test," as referred to by the author. I agree with him that such a test is of very little value. A proper pumping test is a much more elaborate and expensive proposition. The Massachusetts State Board of Health has probably done more in this line of work than has been done anywhere in this country, and, as a result of their careful studies, not only of the results of the pumping tests but the results of the actual operation of the plants after construction, they have become able to so direct the test and to so interpret the results as to determine with practical certainty everything that it is necessary to know before installing the works.

During a pumping test water should be drawn from the ground at a rate at least as great as it is expected that the draft will be after the works are in operation. The test should be continuous and should extend over a period of from a few days to a few weeks, depending upon the results which are obtained. Observation wells should be located in the vicinity and a complete record of the height of the water in the ground at various places should be kept during the test. Samples should be collected at frequent intervals for chemical analysis.

After the test is completed observations on the wells should be

continued to show the recovery of the ground-water level after the draft ceases. With the results of such a test it is possible to foretell whether or not there would be any rapid deterioration of the water with continued draft from the ground and to tell within reasonable limits the quantity of water which the source is likely to yield continuously.

A thorough pumping test is expensive, and in many cases it seems like a waste of money, especially when the tests prove unsatisfactory. There are cases where the conditions can be foretold without a pumping test with such a degree of certainty that a pumping test is unnecessary, but in the great majority of cases in New England the pumping test is very desirable, if not absolutely necessary, and the results show with certainty what may be expected of the source.

MR. FULLER. I do not think that there is really any point at issue between us on the pumping question. In my paper, I have said that I do recommend pumping tests. Their limitations, however, must be clearly recognized if conclusions based upon them are to be depended upon. Mr. Johnson has mentioned the complicated character of the exposures in railroad cuts and elsewhere and emphasized the necessity of complete data, especially that furnished by proper pumping tests. This is in direct line of what I am myself arguing for, namely, that all factors must be taken into account. The geological and physical conditions in the vicinity are vital factors of any water problem and must be given due weight in its consideration. Mr. Johnson and I are standing on the same ground, I think. Perhaps I expressed myself unfortunately in calling attention to certain deficiencies, or to certain things a pumping test does not show, but when Mr. Johnson speaks of a pumping test interpreted properly, that interpretation including a physical and geological examination by an experienced party, I am most heartily and thoroughly in accord with him.

I would like to hear what Mr. Weston has to say with regard to what can be told by a pumping test with regard to iron. That is a point with which I am not particularly familiar.

MR. ROBERT S. WESTON. Regarding the presence of iron, I think there are a good many ground-water supplies in New Eng-

land which showed a practical absence of iron in the beginning, even after a prolonged pumping test, that after ten or fifteen years have shown increases varying from twenty-five to several hundred per cent. That is because the lateral movement of the water through the soil brings a great deal of organic matter to the vicinity of the well, and at that point there is not oxygen enough to burn it as fast as it comes. It accumulates, carbonic acid is produced; the iron is kept in solution, and instead of remaining in the soil in the form of an insoluble iron ore it is gradually dissolved in the well in increasing amount. This is true of a number of supplies, concerning which the speaker showed a table two months ago.*

Again, a pumping test of a short duration may not bring water from beneath a peat bog which may be at some distance away; this water may contain much iron. This phenomenon has been noticed in at least three cases in this state, and as soon as the peat bog water, or the water from beneath the peat bog, gets to the well, even though it comes from a distance, the iron suddenly appears in the supply.

*JOURNAL N. E. W. W. A., Vol. 27, p. 23.

LEPTOMITUS IN DRINKING WATER.

BY ROBERT C. SWEETSER, INSTRUCTOR IN CHEMISTRY, WORCESTER POLYTECHNIC INSTITUTE.

[*Read February 12, 1913.*]

In 1910 the water company which supplies a certain town in Massachusetts built a storage reservoir by damming a small stream which flows through a wooded region. The trees were cut down and removed, and the brush and débris were burned on the bed of the reservoir. None of the soil was removed. The entire area of about 400 acres drained by the stream which feeds the reservoir is uninhabited and covered with a growth of wood. It is inclosed by an impassable wire fence, and the only possible sources of pollution are a few deer, estimated at about sixteen, and smaller game.

In the winter of 1910–11 the reservoir was allowed to fill and no water was drawn from it until the following June. When the gate was opened the water from the outlet pipe was directed upward twenty-five feet or more and then fell in a spray to the bed of the brook, which flowed to another reservoir about one mile below. The course of the brook below the upper reservoir is the original course of the stream before the reservoir was built. The water as it spouted from the gate had a very pronounced and offensive odor, which could easily be detected fifty feet distant. Within a few days a vigorous growth of Leptomitus appeared in the upper portion of the brook, covering the entire bed of the stream in places, and hanging in tufts six inches long from twigs lying in the water. This growth and the strong offensive odor gave the stream a decidedly unsanitary character. It was certainly unusual to see a stream whose character should be the best, judging from the ideal surroundings, assume such an appearance as this. There was, however, no evidence of either the fungus or the odor when the brook reached the lower reservoir, about a mile below. A chemical analysis of the water as it came from the gate gave high nitrogen as free and albuminoid ammonia, high color

and high oxygen consumed. (Table 1.) In other respects the water was about normal. Although the Leptomitus began its growth in the hot weather and flourished during the very hot July of 1911, the water of the brook was quite cold, having a temperature of 50° F. in the upper part of the brook where the growth was heaviest.

TABLE 1.

CHEMICAL ANALYSIS OF BROOK WATER IN JUNE AND JULY, 1911.

Parts per Million.

Number	1	2	3	4	5
Date of collection	6–29–'11	6–29–'11	7–16–'11	7–13–'11	7–13–'11
Color	100	100	110	35	38
Odor	Decidedly putrid	Distinctly vegetable	Distinctly vegetable	Slightly vegetable	Slightly vegetable
Total solids	61.0	58.0	62.0	36.5	42.5
Fixed solids	32.0	30.0	30.5	23.5	27.5
Volatile solids	29.0	28.0	31.5	13.0	15.0
Free ammonia	0.170	0.008	0.024	0.008	0.09
Albuminoid ammonia,	0.598	0.166	0.336	0.120	0.056
Nitrites	0	0	0.0008	0.0004	0.0008
Nitrates	0.11	0.07	0.06	0.05	0.05
Oxygen consumed	14.95	8.20	15.10	5.0	6.40
Chlorine	3.50	4.0	3.0	2.0	3.0

1. Outlet of upper reservoir.
2. Lower end of brook near lower reservoir.
3. Lower end of brook near lower reservoir.
4. Lower reservoir near gate house.
5. Faucet in town.

During the winter and spring months the gate of the upper reservoir was closed and the brook below was dry, the town taking its supply during this time from a lower reservoir. June 20, 1912, the gate was opened and by July 1 there was a heavy growth of Leptomitus in the stream, though the amount was considerably less than that of the previous season. At this time analyses were made of the water near the surface of the reservoir, as it came from the gate, and at the lower end of the brook connecting the two reservoirs. The water near the surface of the reservoir had considerably less color, odor, free ammonia, and

oxygen consumed than the water as it emerged from the gate. In three out of four series of analyses, the free ammonia, which was high in the upper portion of the brook, had almost wholly disappeared in the lower portion after flowing a distance of about one mile. (Table 2.)

TABLE 2.

CHEMICAL ANALYSES OF BROOK WATER IN AUGUST AND SEPTEMBER, 1912.

Parts per Million.

Number	1	2	3	4	5
Date of collection	8–5–'12	8–5–'12	9–17–'12	8–5–'12	8–5–'12
Color, Hazen's scale	55	110	50	48	45
Odor, cold	Very slight vegetable	Decidedly putrid	Slightly putrid	None	None
Odor, hot	Slight vegetable	Decidedly putrid	Distinctly putrid	Very slight vegetable	Very slight vegetable
Total solids	48.0	59.0	51.5	39.0	42.0
Volatile solids	18.0	24.0	30.0	18.0	18.0
Fixed solids	20.0	35.0	21.5	21.0	24.0
Albuminoid ammonia,	0.437	0.440	0.335	0.140	0.115
Free ammonia	0.018	0.440	0.240	0.040	0.005
Nitrites	0	0	0	0.004	0
Nitrates	0.05	0.05	0.075	0.105	0.16
Oxygen consumed	11.80	13.00	13.4	7.56	7.40
Chlorine	1.50	2.0	1.5	2.00	2.00

1. Reservoir No. 5. (Upper reservoir.)
2. Outlet of reservoir No. 5.
3. Outlet of reservoir No. 5.
4. Brook just above sand filters.
5. Outlet of sand filters.

The foul condition of the water from the upper part of the brook is, without question, due to the stagnant water remaining for so long a time in contact with the organic matter in the bottom of the reservoir. This vegetable organic matter dissolved in the water and decomposing in the absence of oxygen was the cause of the formation of free ammonia and the offensive odors. The putrefaction of stagnant water at the bottom of a reservoir is, of course, by no means a rare occurrence, as it happens frequently at Lake Cochituate, Jamaica Pond, and elsewhere.

The burning of the brush on the bed of the reservoir just previous to its being filled would necessarily leave a large amount of partially charred material which is more soluble than the unburned or the completely charred vegetable matter. This very likely increased the amount of organic matter in the water of the reservoir during the first season it was used. Early in the summers of both 1911 and 1912 there was a heavy growth of algæ in the reservoir. It was thought at first that this might be a contributing factor to the Leptomitus growth in the stream below. The algæ, however, soon after disappeared and were absent practically the rest of the season.

Mr. Harrison P. Eddy has quite recently called the author's attention to the conditions accompanying a growth of Leptomitus in the sewage effluent at Marlboro, Mass. Here the growth was so vigorous at one time that it covered the bed of the stream to a depth of four or five inches, but has since practically disappeared. An inspection of the chemical analyses of the samples taken during the whole period when the Leptomitus was present does not show the heaviest growth of the fungus at the times of highest free and albuminoid ammonia. (Table 3.) In general, however, it may be said that since 1910, when the growth was the heaviest, it has

TABLE 3.

SEWAGE EFFLUENT, MARLBORO, MASS.

Parts per Million.

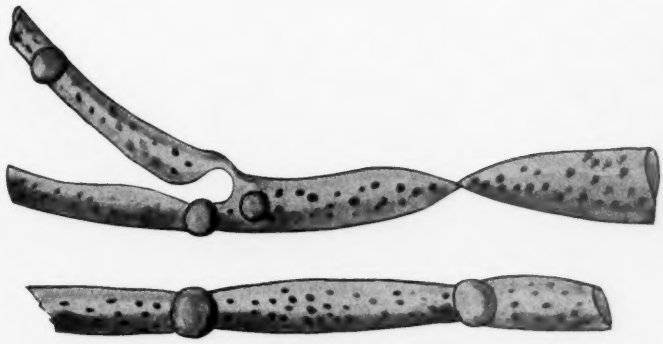
	1908.	1909.	1910.	1911.	1912.
Free ammonia:					
Dec.–May.....	15.98	28.96	16.47	21.73	7.24
June–Nov.....	23.44	25.85	10.59	6.33	2.75
Jan.–Dec.....	22.27	25.70	13.20	12.63	5.05
Albuminoid ammonia:					
Dec.–May.....	0.72	1.43	0.80	1.04	0.44
June–Nov.....	1.21	1.24	0.71	0.29	0.23
Jan.–Dec.....	1.10	1.24	0.75	0.61	0.34
Nitrates:					
Dec.–May.....	1.07	1.15	5.59	5.82	10.24
June–Nov.....	9.09	5.98	19.05	22.72	26.88
Jan.–Dec.....	5.01	4.35	12.56	14.78	18.25
Leptomitus growth .	Small	Medium	Heavy	Medium	Very slight

been disappearing with the gradual improvement of the effluent, that is, as the free and albuminoid ammonia have decreased and the nitrates increased, the Leptomitus has almost disappeared. Another important fact in connection with the growth at Marlboro is that it was much heavier in the colder months. It is also seen from the analyses that, with the exception of 1908, the free and albuminoid ammonia was higher and the nitrates lower during the cold months.

In 1899 the town of Westboro, Mass.,* was troubled with Leptomitus growing on the inner surface of the sewer pipes which conveyed the crude sewage to the filtration works. At times the quantity was so great as to completely obstruct the sewer so that the sewage would flow from the manholes. The sewer was laid for a considerable portion of its length in wet meadow land, and the leakage of ground water into the sewer pipes was excessive, estimated to be more than three times the volume of the sewage. After the rebuilding of the sewer and the exclusion of the greater portion of the ground water, this organism practically disappeared and no further trouble was occasioned by it. At Worcester, Mass., there is a growth of Leptomitus which occurs under conditions similar to those which existed at Westboro. In the early spring the pipe which conveys the raw sewage from the grit chamber to the Imhoff tank becomes clogged with this organism to such an extent that it is necessary to flush it out with a hose. The growth appears at that time of the year when the chemical analysis of the sewage shows it to be diluted to a considerable extent with ground water, which leaks into the pipes. After the pipe is cleaned the growth does not appear again until the following spring.

There seems to be very little literature on the subject of Leptomitus and the conditions favorable to its growth. It is commonly known as a "sewage fungus" and its presence in a stream is considered evidence of sewage pollution in a marked degree. Thresh, in his "Examination of Water and Water Supplies," describes it as "forming tufts of filaments like bits of cotton-wool, though often colored, adhering to stones, twigs, water plants, débris, etc. It is not found in crude sewage, as its growth requires that it should be aërated. It will not flourish in very impure

* Report Massachusetts State Board of Health, 1903, p. 432.



LEPTOMITUS.

Magnified about 750 times.

(After drawing made by J. W. M. Bunker, Ph.D., Harvard University.)

water, but may grow luxuriantly in good sewage effluents." Whipple speaks of it as " being found in pipes conveying sewage, or on the banks of sewage-polluted streams."

As free ammonia in large amounts is always present in streams in which Leptomitus growth occurs, a natural conclusion would be that the free ammonia is in some way responsible for this growth. Their occurrence together can also be explained on the assumption that they both result from the same cause. Fungous growths require organic matter for their food, and it is very probable that more complex decomposition products accompanying the formation of free ammonia are more important factors in the growth of this organism. Such decomposition products if they contain nitrogen are classed as albuminoid ammonia, as this term includes a large number of complex organic compounds, found in water and sewage, representing many stages of decomposition and all degrees of stability. The high free and albuminoid ammonia and the very strong odor in the water from the outlet of the reservoir previously mentioned are decided indications that the organic matter was in a very active state of decomposition. The decrease of the free and albuminoid ammonia and odor, with the disappearance of the Leptomitus in the lower part of the stream leading from the reservoir, might be considered evidence that the albuminoid ammonia exerts an influence on the growth of this fungus. The conditions at Marlboro also indicate that that state of the effluent resulting in the formation of high free and albuminoid ammonia favors the growth of Leptomitus.

Thresh's statement, that Leptomitus requires a well-aërated water, is not perhaps in accordance with our ideas concerning the conditions favorable to its growth. We are familiar with gray fungous growths similar in appearance at least to Leptomitus, in water very foul with putrefying matter. In the work on " Sewage Purification," by Kinnicutt, Winslow, and Pratt, is the following statement: " An interesting change in the fauna and flora accompanies the gradual purification of a stream, and the approximate completion of the task is made obvious, even to the eye, by the characteristics of plant growth. At points of extreme pollution no green growth appears, but only molds and other colorless plants which require organic matter for their food. A grayish or

blackish mass of Leptomitus covers the rocks." My observations, however, made on the outlet of a drinking water reservoir, though limited, seem to confirm Thresh's idea in regard to aëration. This water was forced several feet into the air and fell in a spray to the brook in which were placed miniature dams to provide as much aëration as possible, the object being to remove the foul odor. The bed of the brook is uneven and the heaviest growths appeared in the shallow places and where the water was agitated the most.

Further analyses of the conditions affecting the growth of this fungus give evidence that the free and albuminoid ammonia are not the only factors. In Marlboro, during the years 1908 and 1912, when there was only a small growth of Leptomitus in the effluent, the amount of free and albuminoid ammonia, particularly the free, was higher in some cases than in the outlet of the reservoir in which there was a large growth. Further, the growth in the Marlboro effluent was uniformly heavier in the cold months, but in the year 1908 the ammonias were higher during the warm months. These seeming inconsistencies do not necessarily indicate that the condition of the effluents, as indicated by the high free and albuminoid ammonia, is not a factor in the growth of the Leptomitus, but rather that there are other factors that influence the growth. In Westboro and Worcester, the Leptomitus grew very abundantly in the sewage diluted with a large amount of ground water, but would not grow in the strong sewage. In other words, an increase in the free and albuminoid ammonia was accompanied by the disappearance of this organism. In the outlet of the reservoir and in Marlboro the reverse was true; the fungus grew more abundantly in times of high free and albuminoid ammonia. These constituents of the sewage then apparently are not the sole cause of this growth; there is evidently another factor, and at Westboro this factor was quite conclusively shown to be dilution. Dilution and aëration both produce the same result, both increase the amount of dissolved oxygen in a sewage or water containing a large amount of organic matter. In the four instances cited in which the growth of Leptomitus was observed, there was more or less evidence that dissolved oxygen had a material influence on its growth, and the influence of the free and

albuminoid ammonia in some instances seems to be somewhat obscured and complicated by the amount of dissolved oxygen present.

Heretofore, as far as is known, Leptomitus has not been reported as occurring in drinking water. Although the stream from the reservoir is without doubt unpolluted, its chemical composition is similar in many respects to that of a badly polluted water, the principal difference being that in this water the source of contamination is vegetable putrefying matter instead of animal. Such being the case, Leptomitus might be more properly called a " foul-water fungus " rather than a " sewage fungus."

My conclusions drawn from the observations made of the growth of Leptomitus in the stream formed from the outlet of a reservoir, and from information gathered from other sources, are that aëration or sufficient dilution and free and albuminoid ammonia or organic matter in an active state of decomposition are all favorable to the growth of this fungus. There is also considerable evidence that a low temperature favors its growth. And finally, that Leptomitus is not always an indication of sewage pollution.

The observations upon which these conclusions are based are limited in number and incomplete, and I should be interested to know of observations by others which are either corroborative of or contradictory to them.

It may be interesting to add that while the water as it came from the outlet of the upper reservoir in the town first mentioned had a color of 100–130, and a strong offensive odor, after flowing a mile through the brook to a lower reservoir, and from here through service pipes to the town, its color dropped to 40 and the odor had wholly disappeared. The foul condition of the brook lasted all summer, but the water in the town caused no complaints from the consumers. In an attempt to kill this fungous growth the brook was diverted from its course, and when the growth became troublesome in the brook in its new course, the water was turned back into its original channel, which in the meantime had been thoroughly cleaned. In this way the growth was in a large degree checked. Fragments of Leptomitus were continually becoming detached and floating down stream, and it was feared by

this means the growth might spread to the lower reservoir. To prevent this a wooden sluice-way was constructed in the stream and in this were placed cloth screens. This precaution proved unnecessary, as the growth did not extend down the stream to the screens. Later, sand filters were constructed at the lower end of the brook just as it enters the lower reservoir. There is no sedimentation of water before it runs on to the filters, and there forms on the filters a black deposit of decayed vegetable matter, which is evidently mixed with sufficient Leptomitus which has floated downstream to give the deposit a rather slimy consistency. This clogs the filters badly and necessitates scraping about every two days. The water from the filters is clear and odorless.

DISCUSSION.

PROF. WILLIAM T. SEDGWICK.* It is an old custom showing the early stages of a science, to affirm that a particular thing is the cause of some other thing, and the sole cause. Pasteur, for example, found that what he believed to be "the" vinegar microbe and also "the" microbe that would sour milk. But to-day we know that there are many microbes that will sour milk and quite a number that will feed on alcohol and produce vinegar. Then we used to hear much about "the" sewage fungus Beggiatoa. But we don't hear so much about it nowadays. It is recognized that Beggiatoa may grow in sewage or it may not, and that you cannot be sure that you have got sewage wherever you get Beggiatoa.

And so it has been with Leptomitus. The testimony has been that wherever Leptomitus is, sewage must be, or have lately been. When, therefore, Professor Sweetser told me that he had found Leptomitus in a drinking water stream flowing from a good reservoir, I saw that the Leptomitus myth had got to go; and I was quite ready to see it go, because I have always been skeptical about such simple things as the Leptomitus-sewage doctrine since I began to know about Pasteur and other cases.

Now I think this paper is exceedingly interesting. It is interesting in a great many ways. In the first place, it shows once

* Massachusetts Institute of Technology, Boston, Mass.

more that the bottoms of our reservoirs are, as we know, not infrequently in a condition which to a layman would suggest sewage. Reductions go on there in the absence of oxygen which give rise to excessive amounts of free ammonia and to rearrangements of the albuminoid materials, and also to the diminution of nitrates. In other words, a whole lot of obscure changes are going on in the bottom of these reservoirs, which are now well known, of course, to you gentlemen, and yet when they were first worked out in this neighborhood by Mr. Stearns and Professor Drown and Mrs. Richards, and others, were a great surprise to all of us. You can draw up, as you know, from the bottom of a good many fine looking ponds abominable looking water and abominable smelling water, just as you can sometimes get from deep wells water that is anything but attractive.

And the reason is perfectly clear. There is oftentimes a lack of oxygen down there, and an abundance of microbes or, at least, a sufficient number of microbes capable of living under those conditions, and a lot of chemical changes take place there which yield undesirable and unexpected products. I have no doubt that under certain conditions the outflow taken from the bottom of a good many reservoirs might give support to Leptomitus and other fungi. But here is the first case I know of, reported and studied with thoroughness and painstaking care by Professor Sweetser.

He has raised the question, What is it that supports the Leptomitus? Here again we naturally seek for a simple and easy explanation. I suggested to him that very likely it was the free ammonia. That was as good a guess as any other, because sewage contains free ammonia, and so does water from the bottom of many of our ponds. But, on the other hand, Leptomitus is a fungus, it is destitute of chlorophyll, and fungi ought not to live on free ammonia; they ought not to have much to do with nitrates. They have got to have richer food than either of those. And so we have to turn to the albuminoid ammonia, — that unknown land in which so many chemical compounds exist, and where so many things go on that nobody knows anything about. The things represented by albuminoid ammonia we know very little about; they may be of one sort or another. Apparently they are of many sorts. And it would seem that among these, together with the

presence of oxygen and, perhaps, the presence of considerable free ammonia, chemical rearrangements take place by which this organism gets a natural and necessary food. But what that natural and necessary food is, no man knows. Each organism is more or less delicately adjusted to its environment, and its environment more or less delicately adjusted to it.

When we think of Leptomitus growing near the mouths of sewers, as we find it, for example, in the Nashua River at Fitchburg, down below some of the sewer outfalls, you have got a good deal the condition described by Professor Sweetser as probably requisite, namely, decomposing organic matter, which in a chemical analysis would appear largely as albuminoid ammonia, free ammonia, oxygen brought in by the flowing stream, and dilution. At any rate, never again shall we be able to say that Leptomitus certainly indicates sewage pollution. All we can say is that it apparently means foul water. We don't get it growing in waters even when they are high in albuminoid ammonia or even when they contain a great deal of free ammonia, after they are aërated. We get it, apparently, connected with putrefaction in some way, either putrefaction at the bottom of a reservoir or putrefaction in a sewer.

MR. ROBERT S. WESTON.* I had occasion to observe this Marlboro effluent brook and can testify as to the abundance of growth at one time and to the disappearance of the organisms after the condition was better. I am inclined to think that there must be some condition of the organic matter produced by decomposition in the bottom of a reservoir, where it is in such a condition that it rapidly (with the help of Leptomitus) unites with oxygen, when exposed in a brook. Ordinarily the organic matter, as I understand it, undergoes a rather slow decomposition through the agency of bacteria, but here the fungus seems to take the place of the bacteria and effects a very rapid change in the organic matter which has been prepared by decomposition for the growth or as the food of the Leptomitus.

A man named O. Spitta, in Berlin, has done a great deal of work on the character of the Spree River as it flows through Berlin, and has found around sewer storm overflows in the Spree, where

* Consulting Sanitary Engineer, Boston, Mass.

there has been a good deal of decomposed sewage going into the water, zones of algæ, and these zones, not only of algæ but of fungi, grow right at the outlets of the sewers. It seems as if these cases are analogous to those of Professor Sweetser.

I remember observing when in Beverly last fall with Mr. Blackmer a rather highly contaminated water from a brook draining the bottom of a reservoir, and flowing into a lake, where for a space of 20 ft. out from the point of entrance were numbers of organisms, evidently scavengers waiting for the digested organic matter which was being carried from the brook into this lake. Probably further investigations by Professor Sweetser would show that there is the same preparation of organic matter in the bottom of a reservoir which makes so good a food material for the Leptomitus, that a little aëration causes the two to combine readily and oxidize the water more rapidly than by bacterial oxidation.

PROCEEDINGS.

HOTEL BRUNSWICK,
BOSTON, MASS., February 12, 1913.

The President, Mr. J. Waldo Smith, in the chair.
The following members and guests were present:

HONORARY MEMBERS.

W. T. Sedgwick and F. P. Stearns. — 2.

MEMBERS.

C. H. Baldwin, A. F. Ballou, L. M. Bancroft, G. W. Batchelder, A. E. Blackmer, J. W. Blackmer, C. A. Bogardus, Dexter Brackett, E. C. Brooks, George Cassell, J. C. Chase, R. D. Chase, A. O. Doane, E. D. Eldredge, F. F. Forbes, M. L. Fuller, A. S. Glover, J. A. Gould, F. H. Gunther, R. A. Hale, R. K. Hale, A. R. Hathaway, M. F. Hicks, A. V. Howes, J. L. Hyde, G. R. Jones, F. T. Kemble, E. W. Kent, Willard Kent, G. A. King, N. A. McMillen, A. E. Martin, W. E. Maybury, John Mayo, J. H. Mendell, F. E. Merrill, Leonard Metcalf, H. A. Miller, William Naylor, T. A. Pierce, H. E. Perry, L. C. Robinson, C. W. Sherman, J. Waldo Smith, G. H. Snell, F. N. Speller, G. A. Stacy, R. H. Stearns, E. L. Stone, H. L. Thomas, R. J. Thomas, J. L. Tighe, E. J. Titcomb, G. W. Travis, C. H. Tuttle, W. H. Vaughn, R. S. Weston, F. I. Winslow, G. E. Winslow, I. S. Wood. — 60.

ASSOCIATES.

Builders Iron Foundry, by A. B. Coulters and D. K. Bartlett; Chapman Valve Manufacturing Company, by J. F. Mulgrew; Darling Pump and Manufacturing Company, Ltd., by H. M. Pickersgill; Hersey Manufacturing Company, by Albert S. Glover and W. A. Hersey; Lead Lined Iron Pipe Company, by T. E. Dwyer; Ludlow Valve Manufacturing Company, by A. R. Taylor; H. Mueller Manufacturing Company, by G. A. Caldwell; National Meter Company, by C. H. Baldwin, J. G. Lufkin, and H. L. Weston; Neptune Meter Company, by H. H. Kinsey and R. D. Wertz; Platt Iron Works Company, by F. H. Hayes; Rensselaer Valve Company, by C. L. Brown; Thomson Meter Company, by E. M. Shedd; Union Water Meter Company, by E. K. Otis; Water Works Equipment Company, by W. H. Van Winkle and W. H. Van Winkle, Jr.; R. D. Wood & Co., by H. M. Simons; Henry R. Worthington, by Samuel Harrison and W. F. Bird; National Tube Company, by H. T. Miller. — 24.

GUESTS.

Prof. R. C. Sweetser, Henry C. Page, Worcester, Mass.; George W. Barrett, Lowell, Mass.; Harry Greenhalgh, Fall River, Mass.; E. H. Eldredge, Onset,

Mass.; I. M. Lowe, East Weymouth, Mass.; F. N. Strickland, Westfield, Mass.; George G. Manuel, Natick, Mass.; J. E. Parker, Somerville, Mass., Z. R. Forbes, Brookline, Mass.; and J. Siegel, Cleveland, Ohio. — 11.

The Secretary read the minutes of the annual meeting, and no objection being made, they were declared approved.

An application for membership was presented from M. S. Fuller, Winslow, Me., trustee Kennebec Water District, properly recommended and endorsed by the Executive Committee. The Secretary was instructed to cast the ballot of the Association in favor of the election of Mr. Fuller, and he having done so the gentleman was declared duly elected a member of the Association.

THE PRESIDENT. We all regret that there are not more new members coming into the Association. Those of us who were here last month remember that there was reported a net falling off for the year 1912. This is a matter that the officers of the Association cannot do much about, but it is something that every member should take a vital interest in, and each one of us should try to induce some one to join the Association. I would suggest that before the next meeting we all try and see if we cannot bring in a new member, so that the membership of the Association may be put back to where it was and show an increase.

The Secretary has received the following letter, which I will read:

BUREAU OF WATER.
DEPARTMENT OF PUBLIC WORKS.
CITY OF PHILADELPHIA.

FEBRUARY 10, 1913.

Mr. WILLARD KENT, *Secretary*,
NEW ENGLAND WATER WORKS ASSOCIATION,
TREMONT TEMPLE, BOSTON, MASS.

Dear Sir, — On behalf of the Bureau of Water of this city, I extend a very cordial invitation to the New England Water Works Association to hold its next September convention in Philadelphia.

I do not recall that the Association has ever met in this city, and it is a number of years since it has met in this vicinity.

I think the members of the Association will find a great deal of interest not only in the water supply, but in the city itself.

Very truly yours,
(Signed) CARLETON E. DAVIS,
Chief of Bureau.

At a meeting of the Executive Committee this morning, after views had been expressed by the different members, it was voted to hold the next annual convention in Philadelphia the second week in September, on Wednesday, Thursday, and Friday.

In this connection I may say that I saw Mr. Davis about two weeks ago and he brought the matter to my attention and said that both the director and himself were very much interested and were very anxious that the Association should come to Philadelphia, and that they believed without doubt they could make it not only interesting but very pleasant for the members during three days' stay in the city. It seems to me that it is a very excellent opportunity for us to go there now as there is so much of interest for water-works people in the filtration and pumping plants; and it is a particularly favorable time, perhaps, for one of our members holds a prominent position down there under a reform administration which is trying to do great things for Philadelphia. The mayor is a very interesting man, always very cordial to strangers, and I think those of us who had the pleasure of enjoying the hospitality of the city last fall will heartily endorse our choice of the place for our next annual meeting.

Mr. Brooks has a matter he would like to bring to your attention.

MR. EDWIN C. BROOKS.* I have been requested to ask the following question: "Does any city, town, or water company, where there are two or more tenements in a house, set meters to cover the use of each tenement separately, and if meters are thus set, are the bills made to the owner or to the tenants?" I have been requested to ask if any of the members know of any cases where that is the practice.

MR. GEORGE W. TRAVIS. In Natick we have several such cases, and we insist that the meters be set separately for each tenement. The bills are sent as an accommodation to the tenants but charged to the owners.

MR. FRANCIS T. KEMBLE. We have the same in New Rochelle. We insist on separate meters.

MR. LEWIS M. BANCROFT. The same in Reading.

A MEMBER. The same in Wellesley.

MR. RALPH H. STEARNS. At Hartford meters are only set

* Superintendent Water Works, Cambridge, Mass.

separately for the different apartments of a tenement when requested and the extra meters paid for by the property owners. The bills for water are always rendered to the owners.

MR. WILLIAM NAYLOR. Our rules in Maynard provide that one meter shall be set on a service. If parties want to divide the service we set the meters and charge $1.25 a year for them, we laying the necessary pipe to the meters, and the bills are made out to any one the owner wishes. The owner of the property, however, is held responsible.

THE PRESIDENT. At the annual meeting a report was received from Mr. Baker, the chairman of the Conservation Committee, enclosing a letter from Mr. Pinchot upon the subject of national forest lands, asking that the Association take action favoring the retaining of the control of public forest lands in the national government rather than passing it over to the several states. A vote was passed requesting the chairman of the committee to prepare a resolution to submit at this meeting, and I have the following from Mr. Baker:

505 PEARL STREET, NEW YORK,
FEBRUARY 7, 1913.

Mr. WILLARD KENT, *Secretary*,
NEW ENGLAND WATER WORKS ASSOCIATION,
TREMONT TEMPLE, BOSTON, MASS.

Dear Sir, — In accordance with what I understand was the expressed desire of the Association, at its January meeting, I have drafted a resolution for submission to the Association, against the turning over of national forest lands to the several states. The resolution is as follows:

"*Resolved*, that it is the sense of the members present at this meeting that the public forest lands of the United States should be retained in the control of federal government and should not be turned over to the several states within which such lands are located.

"*Be it further resolved*, that a copy of these resolutions be sent to the Congressmen representing the New England states and to the Congressmen of such other states as the President and Secretary in their discretion may elect."

Respectfully submitted,

(Signed) M. N. BAKER,
Chairman Conservation Committee.

This resolution is proposed for adoption; what will you do with it?

Mr. Frederic P. Stearns moved that the resolution be adopted, and it was adopted by a unanimous vote.

The President then announced that the paper presented at the annual meeting by Robert J. Thomas, on "The Water Works of the City of Lowell and Some Recent Improvements," discussion of which was at that time postponed on account of the lateness of the hour, was now before the Association. The discussion was opened by Mr. Thomas, and was participated in by Mr. F. F. Forbes, Mr. Robert S. Weston, and Mr. R. D. Chase.

Prof. Robert C. Sweetser, Worcester Polytechnic Institute, Worcester, Mass., then read a paper on "The Occurrence of Leptomitus in a Drinking Water Stream." The paper was discussed by Professor Sedgwick and Mr. Robert S. Weston.

A paper prepared by Mr. William R. Conard, inspecting engineer, Burlington, N. J., in the absence of Mr. Conard was read by Mr. George A. Stacy. It was discussed by Mr. Chase, Mr. Leonard Metcalf, and Mr. Robert S. Weston.

Mr. Charles W. Sherman, principal assistant engineer with Metcalf & Eddy, Boston, Mass., gave an account of a visit he recently made to Cuba and a description of certain features of the water-supply plant for the United Fruit Company's plantations.

Mr. Leonard Metcalf called the attention of the members to a matter upon which he was at work, with a committee of the American Water Works Association, in which he desired the assistance of the members of the New England Water Works Association. He said:

"We are trying to assemble information concerning the practice in this country as to charging for private fire protection service. A circular will be sent out by the American Association very shortly, asking for information: first, as to the sizes of taps permitted and the charges made; second, as to the method of locating private fire hydrants; and, third, as to sprinkler systems. I should be very grateful to any of you who will send me a schedule of charges which you have in your works for that class of service. I am very anxious to see what the practice is in different parts of the country, and to see if the practice cannot be standardized.

"I am glad to say that the insurance men have taken a very friendly attitude, and I hope that we can get together on a standard

practice in a way which will be to the advantage of all concerned.

"I may say that in the paper which I presented before the American Association a year or two ago, in connection with Mr. Kuichling and Mr. Hawley, on the reasonable basis for fire protection charges, we were dealing with public fire protection. This inquiry which is now making deals essentially with private fire protection."

THE PRESIDENT. I think this inquiry will bring out a great deal of interesting information, and will show that there is a wide divergence in practice in relation to charging for so-called fire supply. It seems to me, perhaps, the private water companies, who are in the business commercially, will in this case be able to contribute to the general information.

Adjourned.

HOTEL BRUNSWICK,
BOSTON, MASS., March 12, 1913.

The President, Mr. J. Waldo Smith, in the chair.

The following members and guests were present:

MEMBERS.

C. H. Baldwin, A. F. Ballou, L. M. Bancroft, F. A. Barbour, F. K. Betts, A. E. Blackmer, J. W. Blackmer, C. A. Bogardus, Dexter Brackett, G. S. Brown, G. A. Carpenter, J. C. Chase, R. D. Chase, R. C. P. Coggeshall, M. F. Collins, J. H. Cook, J. A. Cushman, E. D. Eldredge, G. F. Evans, F. F. Forbes, A. D. Fuller, M. L. Fuller, F. J. Gifford, A. S. Glover, R. A. Hale, F. E. Hall, A. R. Hathaway, Allen Hazen, H. G. Holden, J. L. Howard, A. C. Howes, J. L. Hyde, W. S. Johnson, E. W. Kent, Willard Kent, Patrick Kieran, G. A. King, Morris Knowles, N. A. McMillen, A. E. Martin, W. E. Maybury, G. F. Merrill, H. A. Miller, William Naylor, F. L. Northrop, T. A. Peirce, L. C. Robinson, P. R. Sanders, A. L. Sawyer, J. Waldo Smith, G. H. Snell, W. F. Sullivan, L. D. Thorpe, J. L. Tighe, D. N. Tower, C. H. Tuttle, W. H. Vaughn, R. S. Weston, G. C. Whipple, G. E. Winslow and H. B. Wood. — 61.

ASSOCIATES.

Builders Iron Foundry, by A. B. Coulters and F. N. Connet; Chapman Valve Manufacturing Company, by C. E. Pratt and J. F. Mulgrew; *Engineering Record*, by I. S. Holbrook; Hersey Manufacturing Company, by Albert S. Glover and W. A. Hersey; Lead Lined Iron Pipe Company, by T. E. Dwyer;

Ludlow Valve Manufacturing Company, by A. R. Taylor; Charles Millar & Son Co., by C. F. Glavin; Mueller Manufacturing Company, by G. A. Caldwell; National Meter Company, by C. H. Baldwin, J. G. Lufkin, and H. L. Weston; Neptune Meter Company, by R. D. Wertz and H. H. Kinsey; Norwood Engineering Company, by C. E. Childs; Pittsburgh Meter Company, by V. E. Arnold and J. N. Turner; Platt Iron Works Company, by F. H. Hayes; Rensselaer Valve Company, by F. S. Bates and C. L. Brown; A. P. Smith Manufacturing Company, by F. L. Northrop; Thomson Meter Company, by E. M. Shedd; Water Works Equipment Company, by W. H. Van Winkle, Jr.; R. D. Wood & Co., by H. M. Simmons; Henry R. Worthington, by W. F. Bird. — 27.

GUESTS.

C. W. Gilbert, Woburn, Mass.; Burt B. Hodgman and O. L. Lincoln, New York, N. Y.; Jack Siegel, Cleveland, Ohio; Robert Robertson, water commissioner, Beverly, Mass.; Harry Greenalch, Fall River, Mass.; J. E. Parker, Somerville, Mass.; F. M. Strickland, Westfield, Mass.; Wm. Tierney, Dayton, Ohio; Frederick E. Tupper, Quincy, Mass.; Arthur E. Hatch, Boston, Mass., and Frank Morsburg, Attleboro, Mass. — 12.

The Secretary presented applications for membership, properly endorsed and recommended by the Executive Committee, from the following:

Thaddeus Merriman, Essex Falls, N. J., assistant to chief engineer, Board of Water Supply, City of New York; Milton W. Davenport, New Britain, Conn., chemist, City of New Britain Water and Sewage Works; Richard H. Gould, Poughkeepsie, N. Y., with R. J. Harding, consulting engineer; J. Stewart Buzby, Moorestown, N. J., principal assistant with W. R. Conard, Burlington, N. J.; Robert C. Sweetser, instructor of chemistry, Worcester Polytechnic Institute, Worcester, Mass.; P. J. Kelley, Salem, Mass., director Public Works; Willard M. Gooding, Berlin, N. H., assistant with R. S. Weston, and acting superintendent, Berlin, N. H., Water Company; Joseph E. Conley, Norwood, Mass., superintendent Sewer and Water Department; William R. Edwards, Paterson, N. J., superintendent Meter Department, Passaic Water Company, Paterson, N. J.; James A. McMurray, Dorchester, Mass., engineer Water Service, Public Works Department, City of Boston; Frank Mossburg, Attleboro, Mass., water commissioner.

On motion of Mr. Thomas A. Peirce, the Secretary was in-

structed to cast the ballot of the Association in favor of the applicants whose names had been read, and he having done so they were declared elected members of the Association.

The report of the Committee on Water Consumption and Statistics Relating Thereto, Leonard Metcalf chairman, Frank J. Gifford, and William F. Sullivan, was then presented. It was discussed by Messrs. Metcalf, Allen Hazen, Morris Knowles, A. F. Ballou.

Mr. George C. Whipple, professor of sanitary engineering, Harvard University, then presented a synopsis of his paper, which was read by its title at the February meeting, on "Decarbonation as a Means of Removing the Corrosive Properties of Water."

Mr. Richard A. Hale moved that the discussion of the paper be postponed until the annual convention in September.

THE PRESIDENT. I think it is important that this paper should receive a full discussion, and between now and the time of the annual convention the paper will have been printed and every one will have had an opportunity to study it and be in position to present such discussion as is desired.

The motion to postpone the discussion was adopted.

Mr. Myron L. Fuller, geological engineer, Boston, Mass., then read a paper entitled, "Quantitative Estimation of Ground Waters for Public Supplies." The paper was discussed by Mr. Allen Hazen, Mr. William S. Johnson, and Mr. R. S. Weston.

THE PRESIDENT. Before the adjournment of this meeting, I want to call attention again to the report which has been presented this afternoon on water consumption and the statistics relating thereto. This Association has always enjoyed an enviable reputation for the high character and the completeness and usefulness of the reports presented from time to time by the special committees; and this report which has been presented this afternoon is not only of great importance but of great interest to every waterworks man. I earnestly request that the members will not put this away in a pigeonhole, but will examine it at an early day, and will communicate their views to the chairman of the committee, Mr. Metcalf, or to the Secretary of the Association, Mr. Kent. It may look rather formidable, but the recommendations are not

so numerous, and certainly every one can examine the recommendations and present his views regarding them.

MR. ALLEN HAZEN. Mr. President, we had a committee on meter rates, some years ago, of which Mr. Coffin was chairman, and he made a report which is a classic. He treated the subject in a way it had never been treated before. But since that time there have been many developments in water-works management, and I think that the time has now arrived when the meter rate question can be taken up and standardized to a greater extent than it has been, with great advantage to the Association. I therefore move that a committee be appointed to take this matter up and to report at some later date.

THE PRESIDENT. How shall the committee be appointed, Mr. Hazen?

MR. HAZEN. Following the custom, I think it would be for the chair to appoint the committee.

THE PRESIDENT. Will you suggest the number of the committee?

MR. HAZEN. I think that will be within the discretion of the President.

The motion was adopted. The President subsequently appointed the following committee: Messrs. Allen Hazen, Charles R. Bettes, Arthur E. Blackmer, Allen W. Cuddeback, and James L. Tighe.

Adjourned.

BASS POINT, June 11, 1913.

The June meeting of the New England Water Works Association was held at Bass Point and Beverly, Mass., on June 11, 1913.

The following members and guests were present:

MEMBERS.

J. M. Anderson, H. B. Andrews, L. M. Bancroft, A. E. Blackmer, J. W. Blackmer, E. C. Brooks, F. L. Cole, John Doyle, E. D. Eldredge, G. F. Evans, M. L. Fuller, T. C. Gleason, A. S. Glover, R. K. Hale, F. E. Hall, G. A. Heffernan, J. L. Howard, A. C. Howes, Willard Kent, G. A. King, C. F. Knowlton, J. N. McKernan, H. V. Macksey, D. E. Makepeace, W. E. Maybury,

John Mayo, F. E. Merrill, H. A. Miller, F. F. Moore, F. L. Northrop, C. D. Peirce, J. J. Philbin, A. L. Sawyer, J. Waldo Smith, Sidney Smith, G. H. Snell, G. A. Stacy, G. T. Staples, R. L. Tarr, E. J. Titcomb, L. J. Wilber, F. B. Wilkins, F. I. Winslow and G. E. Winslow. — 44.

ASSOCIATES.

Ashton Valve Company, by H. H. Ashton; Chapman Valve Manufacturing Company, by H. L. DeWolf; Hersey Manufacturing Company, by Albert S. Glover; Lead Lined Iron Pipe Company, by T. E. Dwyer; Ludlow Valve Manufacturing Company, by A. R. Taylor; Charles Millar & Sons Co., by C. F. Glavin; National Meter Company, by J. G. Lufkin; Neptune Meter Company, by H. H. Kinsey and R. D. Wertz; Pittsburg Meter Company, by J. W. Turner; Rensselaer Valve Company, by C. L. Brown; Ross Valve Manufacturing Company, by Wm. Ross; A. P. Smith Manufacturing Company, by F. L. Northrop and D. F. O'Brien; Thomson Meter Company, by E. M. Shedd; Union Water Meter Company, by F. E. Hall; Water Works Equipment Company, by W. H. Van Winkle, Jr.; R. D. Wood & Co., by H. M. Simons; Henry R. Worthington, by Samuel Harrison and W. T. Bird. — 20.

GUESTS.

Mrs. H. H. Kinsey, Mrs. F. I. Winslow, Mrs. H. A. Miller, Mr. Horace Carpenter, and Mr. V. B. Perry, Boston; Mr. F. S. Hamlin, Mrs. E. C. Brooks, Cambridge; Mrs. G. T. Staples, Miss Grace M. Staples, Dedham; Mrs. L. M. Bancroft, Reading; Mr. Patrick Gear, Miss Catherine Sullivan, Miss Ellen Hanley, Holyoke; Mrs. George E. Winslow, Waltham; Miss Ida Brown, Malden; Mr. Charles Bowman, Mr. Frank E. Smith, Andover; Mrs. John Mayo, Miss Hopkins, Bridgewater; Mrs. G. A. Stacy, Marlboro; Mrs. C. F. Knowlton, Mr. Peter J. Cannon, Clinton; Mrs. W. E. Maybury, Mrs. E. H. Capen, Capt. P. A. Mock, Capt. A. S. Smith, Braintree; Mrs. J. W. Blackmer and Mr. Robert Robertson, Beverly; Master Neddie Eldredge, Onset; Mrs. F. F. Moore, Hawthorne, N. Y.; Mrs. F. B. Wilkins, Milford, N. H.; Mrs. L. G. Wilber, Brockton, Mass.; Mr. F. B. Wilkins, Woonsocket, R. I.; Miss Moye, East Providence, R. I. — 34.

The Secretary read applications for membership, duly approved, from Edmund J. Lonergan, Malden, Mass.; Frank O. Sinclair, Burlington, Vt.; Edgar F. Smith, New York, N. Y.; George H. Hazlehurst, Wilmington, N. C.; and P. A. Shaw, Lancaster, Pa.

The Secretary was empowered to cast the ballot of the Association in favor of the candidates, and, he having done so, they were declared by the President duly elected members of the Association.

EXECUTIVE COMMITTEE.

Meeting of the Executive Committee of the New England Water Works Association at headquarters, Boston, Mass., Wednesday, February 12, 1913.

Present: President J. Waldo Smith, and members M. F. Hicks, G. A. Stacy, J. L. Tighe, J. W. Blackmer, L. M. Bancroft, R. K. Hale, G. A. King, and Willard Kent.

Application of Mr. M. S. Fuller, trustee Kennebec Water District, Waterville, Me., was received and recommended for membership.

Communication was received from Mr. M. N. Baker, chairman of the Committee to look after and keep track of legislation and other matters pertaining to the Conservation, Development and Utilization of the Natural Resources of the Country.

It was voted that the Executive Committee recommends that the Association take the action suggested by Mr. Baker.

Communication was also received from Mr. C. E. Davis, inviting the Association to hold its convention at Philadelphia, Pa., and it was unanimously voted that the next annual convention be held in Philadelphia on the 10th, 11th and 12th of September next, and that the President be and is hereby authorized to appoint a committee of arrangements.

Discussion was had in reference to the June outing and a committee consisting of W. E. Maybury, J. W. Blackmer, and C. W. Sherman was appointed to investigate and report, with recommendations, at the March meeting.

The President was by vote authorized to deputize, at his discretion, both the first and second Vice-Presidents to approve bills and countersign checks on occasions of his absence.

It was voted that no meeting of the Association be held in April of the present year.

Adjourned.

WILLARD KENT, *Secretary.*

Meeting of the Executive Committee of the New England Water Works Association at headquarters, Boston, Mass., March 12, 1913.

Present: President J. Waldo Smith, and members F. A. McInnes, Leonard Metcalf, W. F. Sullivan, G. A. Stacy, J. L. Tighe, J. W. Blackmer, L. M. Bancroft, G. A. King, and Willard Kent.

Ten applications were received and recommended for membership, namely:

For membership: Joseph E. Conley, superintendent Sewer and Water Department, Norwood, Mass.; Robert C. Sweetser, instructor Worcester Polytechnic Institute, Worcester, Mass.; P. J. Kelley, director Public Works, Salem, Mass.; James A. McMurry, engineer water service, Public Works Department, Boston, Mass.; Willard M. Gooding, acting superintendent Water Company, Berlin, N. H.; Frank Mossburg, water commissioner, Attleboro, Mass.; W. R. Edwards, superintendent Meter Department, Passaic Water Company, Paterson, N. J.; Thaddeus Merriman, assistant to chief engineer, Board of Water Supply, New York, N. Y.; Richard H. Gould, sanitary engineer, Poughkeepsie, N. Y., J. Stewart Buzby, inspecting engineer, Moorestown, N. J. — 10.

One member was reinstated.

The President and Secretary were added to the committee on the June meeting, and said committee was authorized to fix the date and place and complete all arrangements therefor.

Adjourned.

WILLARD KENT, *Secretary.*

Meeting of the Executive Committee of the New England Water Works Association on board steamer *King Philip* en route to Beverly, Mass., Wednesday, June 11, 1913.

Present: President J. Waldo Smith, and members George A. Stacy, James W. Blackmer, Willard Kent, Lewis M. Bancroft, Richard K. Hale, and George A. King.

Five applications for membership were received and recommended for admission, namely, Edmund J. Lonergan, Malden, Mass.; Frank O. Sinclair, Burlington, Vt.; Edgar F. Smith, New York, N. Y.; George H. Hazlehurst, Wilmington, N. C.; and P. A. Shaw, Lancaster, Pa.

Adjourned.

WILLARD KENT, *Secretary.*

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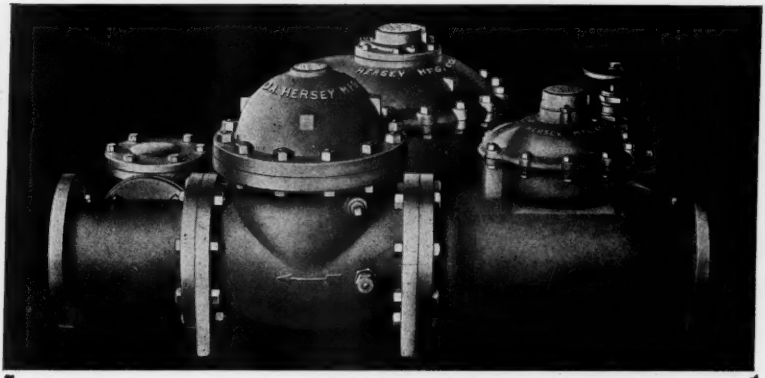

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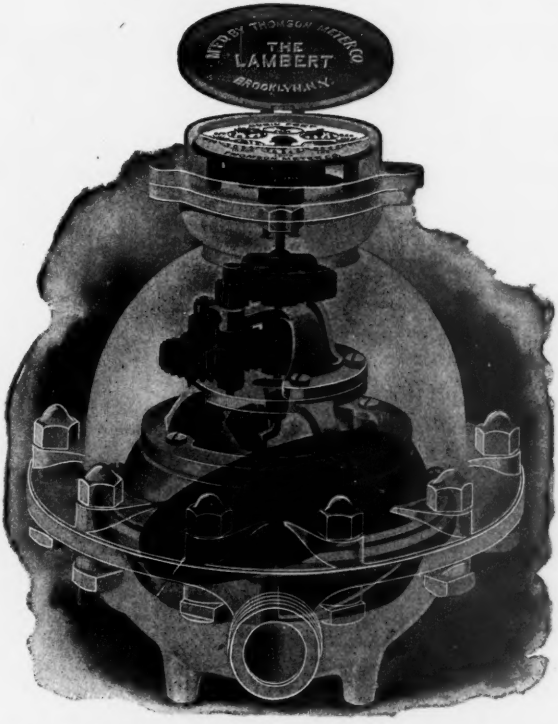

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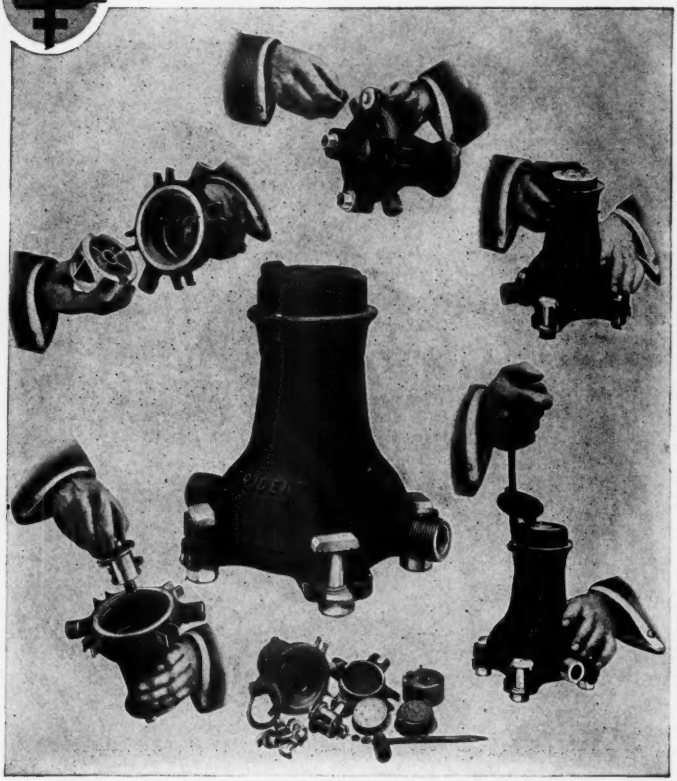

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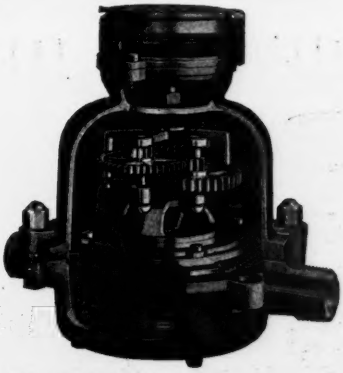

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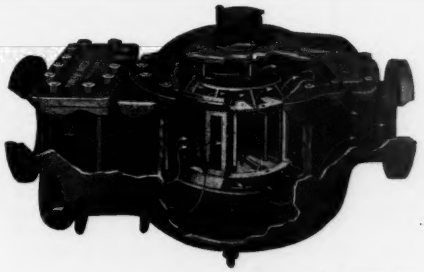

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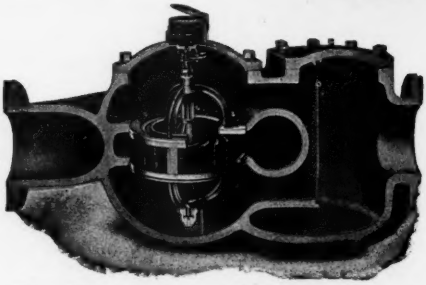

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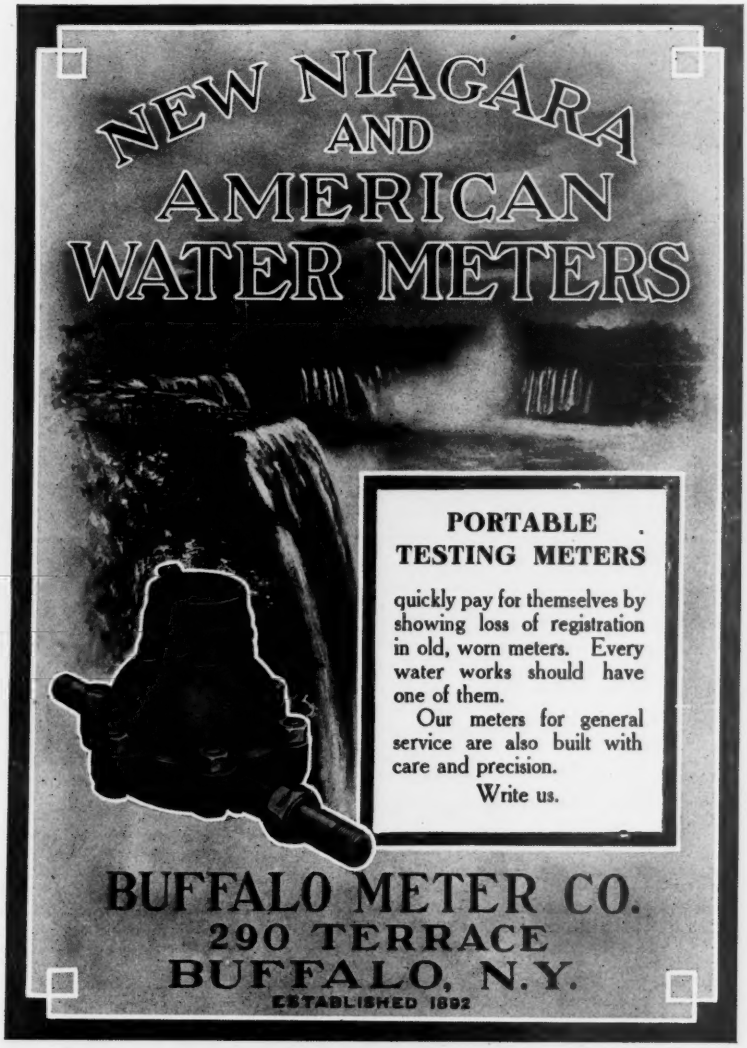
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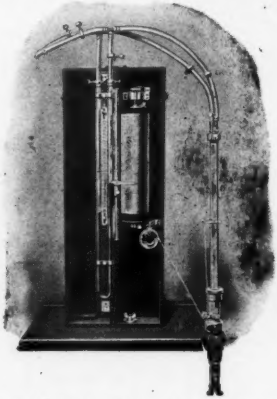

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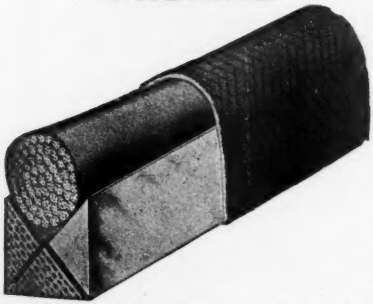

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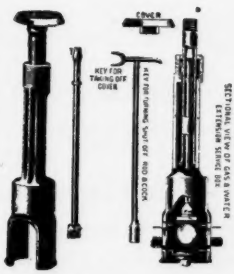

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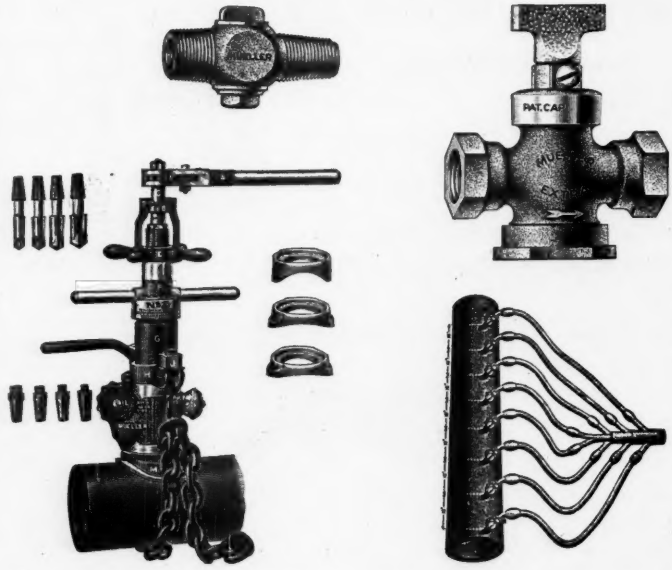

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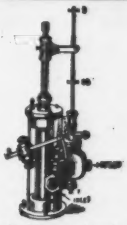

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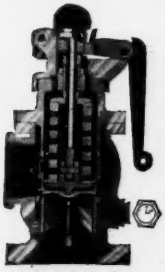

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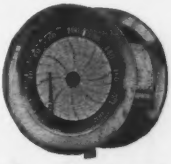

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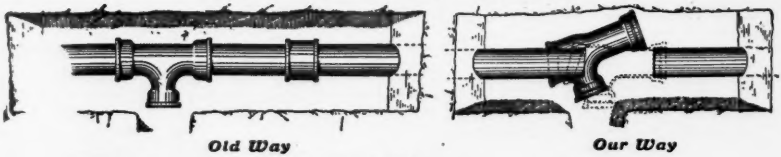

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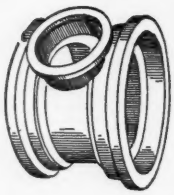

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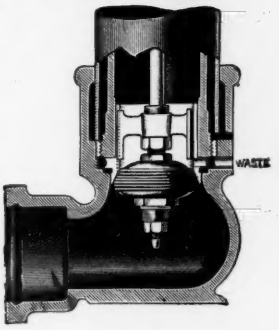

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ANTI-FRICTION
EXTRA WEIGHT, FINISH
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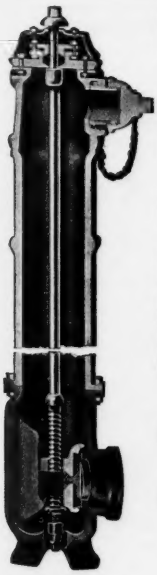

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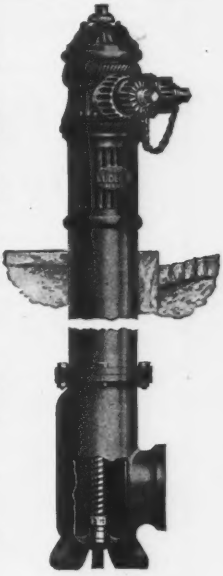

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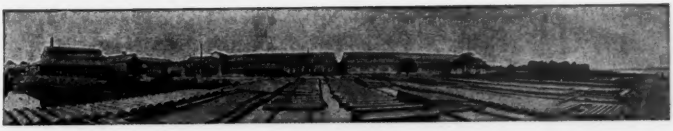

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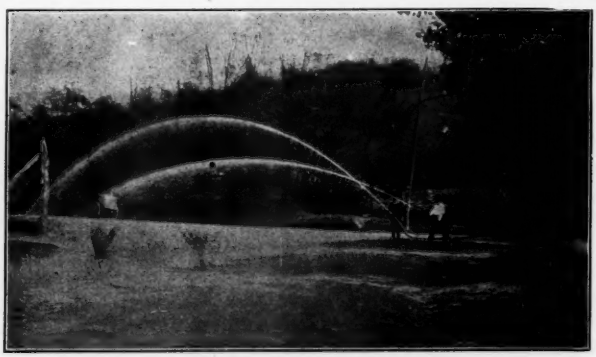
?  ?

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For calking pipe joints under the most difficult conditions.

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Write for a copy of "It Doesn't Affect the Water," which tells all about our proposition and the guarantee that we insist upon making.

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Registered U. S. Patent Office

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Hydraulically and electrically operated valves and sluice gates Valves designed for all kinds of service.

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